United States
Department of
Agriculture

Forest
Service

General
Technical
Report WO-61

Proceedings of the Second and Third Annual Meetings of the International Boreal Forest Research Association

United States
Department of
Agriculture

Forest
Service

General
Technical
Report WO-61

Proceedings of the Second and Third Annual Meetings of the International Boreal Forest Research Association

September 11–18, 1992
Anchorage and Fairbanks, Alaska, USA

September 26–October 2, 1993
Biri, Norway and Umea, Sweden

Sponsors for meetings are:
USDA Forest Service, Washington, DC
Finnish Forest Research Institute, Helsinki
Swedish University of Agricultural Sciences, Umea
Natural Resources Canada, Ottawa
Norwegian Forest Research Institute, Aas
International Forestry Institute, Moscow

The fourth annual meeting was held on
September 25–28, 1994, in Saskatoon,
Saskatchewan, Canada

Sheila Andrus, technical coordinator
Rebecca Nisley, managing editor

Contents

Papers Presented at the Second Annual Meeting of the International Boreal Forest Research Association

September 11–18, 1992
Anchorage and Fairbanks, Alaska, USA

Advance of Pine Beyond the Timber Line in Northernmost Finland During the 20th Century

Gustaf Siren
The Finnish Forest Research Institute, Helsinki, Finland

This report deals with the currently widely recognized phenomenon of advance of pine at the expense of mountain birch in the tundra forest area of northernmost Finland. This change in the structure of the ecosystem has been going on for about a century. With the exception of some minor experiments for purposes of control, the development has been rather free from influences, except for the increased frequency of seed years that seems to be a basic precondition for the present development. In order to provide seed for the afforestation of a 140,000-ha denuded area, a method of producing viable seed of local provenance is presented. Furthermore, the advance of pine is described. The change of dominant tree species seems to improve the class of land utilization.

High-Resolution Remote Sensing for Boreal Forest Monitoring: A Review

A.D. Vyas, Y.Y. Lee, T.B. Cobb, and Sinyan Shen
Natural Resources Management Division, SUPCON International, Woodridge, Illinois, USA

We review the state of the art of remotely sensed data processing for international boreal forest research, in particular, species health and changes in distribution due to climate change and environmental change. Critical evaluation is performed in terms of spatial resolution, ancillary data needs, and configuration of data collection, storage, and processing systems. The availability and types of remotely sensed data in different time frames for time-series studies are assessed. Spatial resolution of sensors including AVHRR (1.1 km), LANDSAT MSS (80 m), LANDSAT TM (30 m), SPOT multispectral (20 m), and SPOT panchromatic (10 m) are analyzed. LANDSAT is found to be necessary for treeline studies. AVHRR is very useful when combined with ancillary data sets such as ecoregion data, terrain data, and climate data. The moderate resolution of the data makes them more accessible to more researchers in terms of storage and processing. Historical LANDSAT data are now more affordable in volume than before. Processing time for boreal species classification using clustering approach were compared for projected 50 MSS scenes. Supercomputers make computation practical when workstations are not for continental areas.

Recent large-scale AVHRR applications—including conterminous U.S. AVHRR data set, land-cover characteristics database for the conterminous U.S., mapping Mexico's forest lands with AVHRR,

and the North American Vegetation Index Map—are reviewed. TM and MSS were compared for different applications. TM data are superior to MSS data for species type identification. However, TM data are not significantly better than MSS data for conifer and hardwood separation. The International Tree Line Project (BLECSCO) is comparing three dates—1970's, 1980's, and 1990's—of LANDSAT MSS and LANDSAT TM data for each path/row along the tree line intercontinentally in Siberia, Lapland, and North America to monitor recent treeline changes. BLECSCO is expanding its scope to employ future acquisition of high-resolution LANDSAT TM data. SPOT data may be included where necessary to provide cloud-free scenes. Data processing and analysis on the super computer are discussed.

Biological Long-Term Evidence of Circumpolar Subarctic Climate Oscillation

Gustaf Siren
The Finnish Forest Research Institute, Helsinki, Finland
Sinyan Shen
Global Warming International Center, SUPCON International, Woodridge, Illinois

The goals of this International Tree Line Project (BLECSCO) are to understand the dynamics of ecosystem response to environmental change and to understand the impact of terrestrial ecosystems on global climate. The near-term objectives of this study are to

- Assess (with state-of-the-art methods) the potential for increase in forest area and forest product resources as a result of global warming in the most climate-sensitive areas of the circumpolar zone.
- Assemble the best interdisciplinary scientific team for establishing the standards of data needed in utilizing the biological information contained between the forest line and the tree line for the above goals.

The approach uses the following techniques:

1. Observations of changes in seed year frequency, which is a strong function of the climatic oscillation.
2. Measurements of coniferous seedling advancement (following the cluster convention for definition of boundary of the forest line).
3. Standard sowing areas for providing forest ground truth along transects perpendicular to the present forest line.
4. Monitoring the correlation between ground truth with NOAA, NASA, and Canadian Center for Remote Sensing's remote sensing imagery.
5. Analysis of length and variation in growing season with non-destructive tree-ring width measurements near the tree line and the forest line.
6. Meteorological measurements to define the changes in climatic external variable in relation to the tree's photoperiod for assessing the increase in forest resources in the most climate-sensitive areas of the Northern Hemisphere.

This project represents a comprehensive

scientific study to obtain hard facts on ecosystem responses to environmental change near the tree line, where the ecosystem is most sensitive to climate changes. The Tree-Line Project will establish international scientific conventions for the determination of the boundaries of forest (forest line) and trees (tree line) for the circumpolar subarctic region, and the necessary calibration and standardization of methods, which will lead to the determination of the quantity and quality of new forest resources and the effective use of forest vegetation as barometers for long-term climate oscillations.

Scientists of the eight nations (United States, Russia, Canada, Sweden, Iceland, Norway, Greenland, and Finland) adopted the name BLECSCO (biological long-term evidence of the circumpolar subarctic climate oscillation; in Swedish *blecst* means lightning) as a short form for the International Tree Line Project at the project's meeting at the University of Helsinki for this collaborative activity on the greenhouse-climate-induced response of the subarctic circumpolar tree and forest line.

Characterizing Boreal Vegetation Ecosystems With Satellite Images and Ancillary Data

Kenneth C. Winterberger and Frederic R. Larson
USDA Forest Service, Pacific Northwest Research Station, Inventory and Economics Program, Anchorage, Alaska, USA

Carl Markon and Mark Shasby
USDI Geological Survey, National Mapping Division, EROS Alaska Field Office, Anchorage, Alaska, USA

The USDA Forest Service has been conducting resource inventories of the boreal forest region in Alaska since the early 1960's. In 1980, the USDA Forest Service Pacific Northwest Research Station initiated a cooperative research program with the EROS Alaska Field Office to evaluate the potential use of remotely sensed data for the assessment of vegetation conditions in the boreal landscape. Research has included digital analysis of MSS data from LANDSAT, SPOT, and NOAA polar orbiting satellites. Recently, investigations related to the characterization of the landscape in boreal regions through the development of regional biweekly composites of advanced very-high-resolution radiometer (AVHRR) data for the 1990, 1991, and 1992 growing seasons have demonstrated the utility of these data for assessing vegetation conditions in Alaska and on a global basis. Greenness indices and related parameters, such as onset, duration, peak, and mean, have been shown to be useful when analyzed along with other data, such as terrain and physiographic regions, for vegetation mapping and characterization of ecological units in support of ecological land classification.

Mapping Forest Distributions With AVHRR Data

David L. Evans and Zhiliang Zhu
USDA Forest Service, Southern Forest Experiment Station, Forest Inventory and Analysis, Starkville, Mississippi, USA

Kenneth C. Winterberger
USDA Forest Service, Pacific Northwest Research Station, Inventory and Economics, Anchorage, Alaska, USA

A map of forest cover for the United States is being produced by digital analysis of advanced very-high-resolution radiometer (AVHRR) data. The Southern Forest Experiment Station's Forest Inventory and Analysis (SO-FIA) Unit is completing work on the lower 48 states and Hawaii. Alaska is being mapped in a cooperative effort between the Alaska Inventory Unit of the Pacific Northwest Research Station and SO-FIA. LANDSAT Thematic Mapper (TM) data were coregistered to AVHRR data to develop models for derivation of forest density within AVHRR picture elements. This process was repeated for major physiographic regions of the United States. The forest density models were then used with spectral classifications of combined biweekly compositions of AVHRR data of identify forest cover. These or similar techniques would be appropriate for boreal forest assessments at continental or global scales.

Siberian Dendroclimatic Project: Network in Boreal Forests, First Results, Perspectives, and Applications in Environmental Science

Eugeni Vagano and S. Shiyatov
Krasnoyarsk Institute of Wood, Krasnoyarsk, Russia

In this paper the position of spatial-temporal dendroclimatic research of boreal forests in Siberia within the Global Change Program is considered.

Two of the existing levels of the reaction of woody species and other plants to climatic change were chosen: tree growth response and stand response; both have exact temporal characteristics (season, several years, and decades). Extensive dendroclimatic work in Siberia should create experimental and theoretical bases. This work consists of (1) building of long-term chronologies for different genera for different growth sites; (2) elaboration of statistic and simulation models describing reaction of tree growth on climate variations; (3) dendroclimatic zonations of Siberian boreal forests; (4) scenarios of climate and anthropogenic changes that affect tree growth; and (5) climate changes reconstruction in the past. First results of a 2-year expedition to collect samples along the circumpolar belt and their application are considered and discussed

Boreal Forests of Russia: State-of-the-Art and Forecasting

Valery I. Shubin
Ministry of Ecology and National Research, Committee for Forestry
Moscow, Russia

The boreal forest of Russia is an important planetary resource, providing biosphere stability, forest products, and ecological and public values for the planet. This importance results from the vast size of Russian forests and their essential contribution to the biosphere (Russian forests store no less than 40.1 T of carbon, and annual carbon accumulation is estimated to 0.5 to 0.6.10 T). The forests of Russia (85% of which are boreal) regulate climatic and water regimes, prevent soil degradation on large areas that are important to the Russian economy, and maintain gene pools of flora and fauna.

This paper describes characteristics of the resource potentials, and ecological and public functions of Russian forests. Their dynamics for the past 40 years are analyzed; trends and the scale of industrial impact are discussed; and positive and negative influences that affect the status of and changes in the forest cover are evaluated.

Specifics and forest policy targets are given in the paper as well as trends for improving the state system for management of forest resources under the recent modern conditions of Russian development. Potentials and possible trends of international cooperation in protection and rational use of forest resources are described.

Expert Systems on the Basis of GIS "Carbon Ecosphere": ALAS, Its Principles and Structure

Alexander S. Isaev and V.A. Rozkhov
International Forest Institute, Moscow, Russia

Theodore Vinson and Tatyana P. Kolchugina
Oregon State University, Corvallis, Oregon, USA

Anatoly Z. Shvidenko
International Institute for Applied Systems Analysis, Forest Research Project, Laxenburg, Austria

ALAS is an expert system (ES) for evaluating the carbon cycle in boreal ecosystems. The components include an information system (IS), an artificial intelligence system, databases, knowledge bases, and automated cartography. The thematic basis of ES is constituted by the following databanks: "Atmosphere", "Biosphere,"

"Pedosphere," "Hydrosphere," and "Lithosphere," which are organized by a common address (eco-regional) file. The cartographic base is presented by digital maps of production, soils, vegetation (in particular, forests). The ES object is a parametric "intersection by base S" of the mentioned database as applied to base territorial units that are the result of the map overlay. ES is constructed on the basis of the principle of expanding model representation with information of knowledge base and expert estimations. We hope that the proposed approach could be implemented for the circumpolar boreal zone within the framework of IBFRA activities.

Boreal Forest Pathology Monitoring

Nickolay P. Pavlinov
Forestry Commission of Russia, Office of Forest Protection, Moscow, Russia

In the current year, the "Act on Environment Protection" has been adopted in Russia. The act determines the tasks and trends of the work of all agencies responsible for nature protection. The Russian Forest Committee is responsible for monitoring of forest resources. One of the components of the work is monitoring the health of the forests, including work to survey the number and extent of the Siberian silk moth, *Dendrolimus sibiricus* L., and its effects on forest ecology.

Surveys for this insect and other pests are based on the landscape-typology and evaluate their status between outbreaks. This resulted in decreases of the area for forest health monitoring by 2 to 3 times. Key points for survey are determined by forest inventory data and by spectrasonal aerial photography when necessary.

The large scale of the boreal forest zone in Russia requires monitoring of many diverse species and phenomena. First of all, the health of the forest is observed after fires, harvesting, and damage by leaf-eating insects and bark beetles. Also, in the boreal forest zone there are many industrial plants that affect forest dieback because of their emissions into the air, resulting in additional monitoring needs.

Key points for pathological monitoring do not coincide with the network of general forest monitoring. This is why it is necessary to unite data for stand, air, and atmospheric monitoring to obtain reliable results.

System Analysis of Forest Monitoring

Anatoly Z. Shvidenko
International Institute for Applied Systems Analysis, Forest Resources Project, Laxenburg, Austria

Alexander S. Isaev and V.I. Sukhih
International Forestry Institute, Moscow, Russia

In this paper, we analyze the currently used system for forest monitoring of boreal forest zones in order to coordinate the Russian national system of forest monitoring.

Forest monitoring in Russia is the systematic long-term survey of forests and lands of the Forest Fund, the purpose of which is to provide data for rational management policy, forest resource assessments, and evaluations of land-use changes. While analyzing definitions, coordination of the goals and ways of their fulfillment, it is shown to be feasible to understand monitoring as a united information system (levels as global, national, regional, and local), goals for each level, measured and evaluated variables (indexes) and their requirements, information technologies, communications links, system limitations,and ways for optimization. The recommended terrain zones are described (continent, country, zone province, region, and district) united by common landscape approach (landscape = genetically separated part of the landscape, region, or any other large regional unit), characterized homogeneously in zone and azonal respect and having individual structure. General classification of forest vegetation (according to criteria from UNESCO, FAO, or national organizations) is given and possibilities for its use at the top levels of the system are shown.

Boreal Forests: Problems of Learning

Alexander S. Isaev
International Forestry Institute, Moscow, Russia

Although the global importance of the boreal forests is being increasingly recognized, the level of knowledge of the processes going on the boreal forest is poor, especially their role in the biosphere, and the reliability of data on forest conditions, economics, and prognosis for the future. This is so because of the relatively poor attitude of the Government and international and national research institutes, the large-sized territories with their undeveloped infrastructures, and the lack of needed environmental monitoring, etc. The general state of uncertainty in Russia is also an essential ingredient affecting the reliability of data on forest conditions, phytomass, and productivity evaluation, anthropogenic activity, etc.

In this paper, methodology, information models, and the organizational and scientific aspects of the process of learning about boreal forests are presented from a world-scale view. Basic principles for establishing this learning are formulated (system technique as a temporary analog of theoretical nations, compression, universalization of descriptive languages, etc.).

The necessity for modernization of general approaches to processes modeling and the use of adequate to nature mathematical models are shown (conflict theory, theory of possibilities, etc.). The information network is evaluated, and options for international research work in boreal forests are proposed.

Long-Term Monitoring of Boreal Forests Using Fossil Pollen Records: The Past as Prologue to the Future

Glen M. MacDonald
McMaster University, Geography Department, Hamilton, Ontario, Canada

Fossil pollen can provide important retrospective data on past climate change and the resulting response to vegetation. This can be a useful way of extending monitoring records for boreal forests from decades to millennia. Such long records can provide data for developing, parameterizing, and testing ecosystem models and are particularly important for the studies of the potential impact of global climate change. The temporal resolution of pollen records ranges from centuries to individual years. The spatial resolution can vary from a few hectares to thousands of square kilometers. There are three important areas where fossil pollen data can contribute to predicting, detecting, and managing the impact of future climate warming. First, fossil pollen records can provide baseline data on the natural variation experienced by climate and ecosystems by thousands of years. Second, pollen records can be compared both inter- and intraregionally to document the degree of synchrony of past climate change. This information can be used to predict the potential regional differences in the timing and rates of future climate change. Finally, fossil pollen records can be compared with data on past climate changes to assess the potential patterns and rates of vegetation response to future climatic change.

Integration of Boreal Ecosystem-Process Models Within a Prognostic Carbon Budget Model for Canada

David T. Price and Michael J. Apps
Natural Resources Canada, Northern Forestry Centre, Edmonton, Canada

Prediction of long-term (100-year) national-scale carbon budgets requires comprehensive assessment both carbon pools (aerial distributions and magnitudes) and of the processes affecting carbon fluxes among them. Although we can achieve the former from inventories and other statistical records, there are major problems inherent in modeling ecosystem processes at this scale. Yet, without realistic, appropriately scaled representations of ecosystem responses to anticipated changes in CO_2 concentration and climatic regimes, the resulting estimates of future carbon budgets may be very misleading.

This paper discusses problems involved in linking process-based models of ecosystem dynamics (net primary productivity and vegetation competition, influenced by dis-

turbances and management) to Forestry Canada's national carbon budget model. Using the Canadian boreal forest as a case study of national importance, we propose that simulations of response surfaces generated by many types of process models can be used to formulate "metamodels" of ecosystem responses (net primary productivity and vegetation competition, influenced by disturbances and management), which may then be used by the national carbon budget model as substitutes for real input data. This metamodel concept should form a scientifically acceptable means of scaling from discrete field measurements and validated small-scale process-based models, up to regional and national forest-sector carbon budget models, usable by policymakers for long-term predictions of carbon budgets with significantly increased confidence.

NBIOME: A Biome-Level Study of Biospheric Response and Feedback to Potential Climatic Change

Michael J. Apps on behalf of the NBIOME Science Steering Committee
Natural Resources Canada, Northern Forestry Centre, Edmonton, Alberta, Canada

The potential for significant climate changes in northern latitudes over the next century poses numerous challenges for Canadian resource managers, researchers, and citizens. Prognostic capability to guide the formulation of appropriate resource management policies requires improvement in contemporary understanding of (1) the likely response of northern terrestrial ecosystems to a rapidly changing climate and (2) the dynamic role of these systems in modifying climate system (feedbacks). This understanding must be developed over a demanding range of spatial and temporal scales.

Process observations and detailed ecophysiological theories at the level of individual ecosystems may be used to delineate the critical process controls on system response at these scales but to meet the prognostic needs of policy makers and resource managers, this detailed understanding must be scaled up to the biome and global level. This biome-level formulation must permit examination of both short-term (decades) and medium-term (ca. 100 year) implications of alternative climate change and resource management scenarios. This paper outlines the science plan for NBIOME (the Northern Biosphere Observation and Modeling Experiment), a collaborative, interdisciplinary project developed for Canada's forests, wetlands, and agro-ecosystems by university and government agency scientists from across the country. Combining observations over a wide range of scales with integrating models of ecosystem structure, function, and response, NBIOME will focus on the likely effects of global environmental changes on three interacting aspects of these terrestrial ecosystems: (1) the role of disturbance regimes in shaping spatial and temporal patterns of structure and function, (2) the changes in changes in vegetation distribution and dynamics, and (3) the size and changes of terrestrial carbon pools and the net exchanges of important greenhouse gases with the atmosphere.

Forest Status in Norway: Research, Inventory, and Forest Monitoring

T. Opheim
Royal Norwegian Ministry of Agriculture, Oslo, Norway

S. Nersten
Department of Forestry, University of Norway

O.J. Wefald
Norges Skogeierforbund, Oslo, Norway

Hans-Olav Moen
Norwegian Forest Research Institute, Aas, Norway

Norway is a country with a significant variation in climate, ecology, and forest growth conditions. The country includes both two temperate zone and boreal zone forests. The productive forest land amounts to 7 million hectares, one fourth of the land area. The average productivity is, roughly estimated, 4 m^3 per hectare. The annual cutting is 10 to 12 million m^3. The productivity has increased 70% from 1920 to 1990, due to cooperation between the forest owners and the state, and to forest research. Eighty-seven percent of forested land is privately owned; the remaining 10% is owned by the state and 3% by the municipalities.

Forest research in Norway began in 1916. Today the research consists of biological, technical, and economical aspects of the utilization of forest resources. The annual research budget amounts to 12 million US dollars and 185 persons are engaged in research work. The Norwegian Forest Research Institute and the Faculty of Forestry of the Agricultural University of Norway have formalized cooperation in research and education.

Long-term forecasts of the wood supply have been made several times, the latest in 1981. The sixth national forest inventory has just been started. In addition to the conventional review of the forest resources, long-term forecasts of the timber supply in each country are planned to (1) give a good basis for political decisions and (2) plan new forest industry in the future.

Since 1987 the Norwegian Forest Research Institute has been the focal center of forest monitoring in Norway. A network has been established to give information on forest vitality or state of health, as measured by crown density and crown color. This monitoring program is part of the monitoring program UN/ECE "ICP Forests." A special monitoring program has been established in Finnmark, the most northeastern part of Norway, in order to follow the forest situation close to the industrial activity in Russia. In addition, the institute participates in general monitoring of terrestrial ecosystem.

The Swedish National Forest Inventory: Current Design and Plans for the Future

Bo Ranneby
Swedish University of Agricultural Sciences, Department of Forest Survey, Umea, Sweden

The National Forest Inventory (NFI) provides a basis for the development and evaluation of forest polices in Sweden. It provides necessary information to organizations and governmental agencies for use in strategic planning and control of forest utilization. The NFI also provides unique possibilities for identifying and documenting change in our forests and in our environment in general, within the framework of intensified environmental monitoring.

The NFI is formulated in 10-year periods, called inventory cycles. The ongoing inventory covers the period 1983–92. The inventory is based on both permanent and temporary plots. The design is systematic cluster sampling with partial replacement of plots. The information recorded comprises both site, stand and tree data. All data are recorded by portable microcomputers directly in the field.

The plans for the next 10-year period (1993–2002) are based on demands for the survey to present data about forest conditions for smaller geographic areas than has hitherto been possible, and for better environmental monitoring throughout the country. The NFI can play an important role when it comes to obtaining better information about the health of the forests their vitality or demands as well as about various environmental conditions beyond the those purely concerned with forestry, such as conditions in national parks, reserves, and the high mountains.

Remote sensing techniques within forestry are developing rapidly, and we have now reached the point where it may be feasible to incorporate satellite data into the NFI. These techniques contain a great potential for improving the survey.

One significantly advantage of an integration of remote sensing into the NFI is that it gives rise to a new type of information. Stand-related information can be presented for any area of the country. With the aid of additional field measurements, the degree of detail can be successively refiined.

The Dynamics of Reforestation in the European North of Russia

Vasily F. Tsvetkov
Arkhangelsk Forest and Forest Chemistry Institute, Arkhangelsk, Russia

Intensive commercial clearcutting in the European North of Russia has caused wide-scale changes in forest cover. Secondary forests are characterized by great diversity of structure, growth, and productivity. The technology and season of cutting of primary stands, ecological requirements, and natural forest site are the most significant factors affecting secondary stand formation. The combination of different elements of the given factors provides for a rather pronounced dynamic line of forest regeneration and new stand development.To develop the dynamic typology of Russian northern forests, the dynamic lines of forest formation after clearcutting in most represented types of pine and spruce forests were analyzed. The dynamic lines of the same forest types on the Kola Peninsula and in the middle taiga subzone were compared. Six typological lines of forest regeneration and stand development within the pine forest types in the Far North, were distinguished in the middle taiga. Productivities of every stand development line were estimated and compared.

Dendroclimatology and Global Change in Alaska and Canada

Gordon C. Jacoby and Roseanne D. D'Arrigo
Lamont-Doherty Geological Observatory, Tree-Ring Laboratory, Palisades, New York, USA

The forest tundra ecotone and the boreal forests of North America are two regions of extensive present and potential modification in response to climatic change. Tree-ring analysis in both regions relates to questions of forest changes and long-term records of climatic change. Ring-width data from the forest tundra ecotones document the unusual warming over the past century relative to the past 300 years, even the past 1,000 years in one area. Tree-ring density data show the trends in summer temperatures and reveal that until recently most of the warming has been for the colder seasons, in agreement with recorded and correlate with sea surface temperatures and large-scale phenomena such as the southern oscillation index (SIO). Both maritime and continental tree ring data should be used to extend the climatic record for regional and large-scale climates. First efforts for large-scale temperature records show the warming for northern North American and the Arctic regions.

Forest tundra transition areas show recent

northward and upward shifting of the tree line, and in some areas the northern boreal forests show an infilling of previously open forests. Ring widths at selected sites show substantial increase in absolute terms of radial growth. However, the boreal forests in general do not appear to show substantial increases in radial growth in absolute terms. Full evaluation of these extensive regions requires more analysis. There are also negative aspects to the effects of warming on the boreal forests. In certain drier sites, increased moisture stress may adversely affect tree growth and survival. There are some indications of other stress increases due to disease, insects, and fire frequency. Many of these stress factors require study to determine local and regional effects on the boreal forests. Population expansion, tourism, and the demand for forest products are additional stresses.

Tree-ring data qualify and extend the record of climatic variation and can qualify recent growth changes. Although a general warming is established, vast areas of the boreal regions are unstudied as to local climatic shifts or growth changes in different ecoregions.

North-Russian Forests: Their State, Management, and Reforestation

Vasily F. Tsvetkov
Arkhangelsk Forest and Forest Chemistry Institute, Arkhangelsk, Russia

In this paper, the general characteristics of the geography, structure, and productivity of North-Russian forests are described. The northern forest belt includes the zone of pretundra forests and the middle and northern taiga subzones. The southern taiga, where forest biocenoses are inferior to biocenoses of other vegetation types, is not included in the region. The southern boundaries in Europe are situated on the 60th latitude; in Asia, on the 59th to 58th; in the east, on the 56th to 55th.

More than 80% of the territory is occupied by forest vegetation, and 75% of the wood resources of Russia are concentrated there. The natural conditions are rather diverse. The severity of climate increases from the west to the east. On the territory, zonality is well pronounced. Forest vegetation is represented by several biomorph types with different combinations of forms of vital strategies. In the Forest Fund, 20 to 30% of the area is occupied by bogs and 20 to 45% of forest cover is bogged stands. This forest belt comprises partly or fully many valuable tree species: *Pinus silvestris* L., *Picea exelsa* Link., *P. obovata* Ledeb., *Larix sukaczewii* Djil. Dyl., *L. sibirica* Ledeb., *L. dahurica* Turcz. et Trautv., and *Pinus sibirica* Du Tour.

Within the belt, forest vegetation is differentiated according to seven physical–geographical *oblasts* (or regions): the Kola Mountains, the subarctic taiga, the northeastern European Plain, the North-Ural Mountains, the northern East-Siberian Plain, the northern Middle-Siberian Mountains, the northern East-Siberian Mountains, and the northern Far Eastern Mountains. In the paper, brief characteristics of the forest oblasts are given.

The Anthropogenic Dynamics of Forests on the Kola Peninsula

Vasily F. Tsvetkov
Arkhangelsk Forest and Forest Chemistry Institute, Arkhangelsk, Russia

Data from the Forest Fund and long-term investigations were analyzed to determine the main changes of forest in the Kola Peninsula. The tendencies of the forest to change as forest management intensified and industrial land expansion increased were determined.

Cuttings and fires change the character of forests most of all. Most pronounced changes took place in the last decades, when the excessive forest exploitation in the region was accompanied by high inflammability. In the last 30 years, the anthropogenic dynamics have also included such factors as aerotechnogenic pollution, recreational loadings, and land set-asides for agricultural and industrial uses.

The structure of forest areas changes quickly. The area of mature stands is reduced, especially in pine stands; the share of young secondary stands increases. After the cuttings of 1930–1960, which were done without heavy machines, rather productive young forests of pine have been formed in most productive stands. On cut-over areas of the last decades, the quality of young forests is unsatisfactory. An intensive change of conifers to deciduous species took place. About 15,000 ha were lost and about 90,000 ha were heavily damaged under the influence of atmospheric pollution.

The Dynamics of Boreal Forest Ecosystems in the European North of Russia

Genrikh A. Chibisov
Arkhangelsk Forest and Forest Chemistry Institute, Arkhangelsk, Russia

The natural (endogenous) and anthropogenic (exogenic) successions are characteristic of forests in the European North. Due to the prolonged and intensive impact of clearcutting and forest fires, the formation of anthropogenic forests is the leading characteristic phenomena in space and time. The formation of anthropogenic forests with species successions has acquired the nature of a geographic phenomenon.

One should distinguish between the succession of species and the succession of species composition of forests. The succession of species composition of forest ecosystems is a dynamic forest-forming process.

Depending on the nature of forest regeneration and its duration and intensity, forest-forming processes, forest morphostructure (composition, biological density, and texture), and biocenotic peculiarities can be noted. According to the degree of anthro-

pogenic influence and origin, 3 main types of forest-forming processes can be distinguished (these in turn depend on the following forest-forming factors—extensive clearcutting and forest fires, partial final cuttings, and artificial forest regeneration).

The first type of forest formation is remarkable for the greatest diversity of succession lines beginning from types of clearings. It is reasonable, taking into consideration general signs of forest type singling out and depending on the type of forest formation, to classify anthropogenic ecosystems as types of biocenoses (the basis for their determination is tree species composition).

The biogeocenotic type reflects structural and functional peculiarities of stands and their dynamics on the whole, as well as tendencies and rates of the species composition succession. The nature of interrelations between two qualitative states, resistance, degree of changes, and growth intensity depend on the boreal forest subzone, forest site (first of all, edaphic conditions), biological density, participation of species in species composition, and origin.

The classification of anthropogenic forests according to phytocenotic signs makes monitoring of forest ecosystems and prediction of their dynamics simpler and more accurate and allows better planning of reforestation and forest management.

Biodiversity, Natural Dynamics, and Forest Management in Boreal Forest Ecosystems

Olle Zackrisson
Swedish University of Agricultural Sciences, Department of Forest Site Research, Faculty of Forestry, Umea, Sweden

Modern forestry practices are in use on more than 97% of the productive forest area in Sweden. The use of timber resources has had a negative influence on biodiversity, leading to a long list of endangered species and strong criticism from society.

Forestry in Sweden is today standing at a breaking point. A sustainable use of timber resources must in the future also include other biological values. An important goal for future forestry is to develop silviculture that follows the natural reproduction patterns and processes found in the boreal forest landscape. Therefore, a deeper understanding of the biological processes involved in natural stand dynamics is needed. Evolutionarily important ecological patterns must also be followed if biodiversity is to be maintained.

Both natural stand dynamics caused by forest fires and long-term stability without stand perturbations have been important components found in the landscape. The ecological significance of natural fire-free refuges is poorly recognized and qualified. The ecological importance of dead wood is another key issue that has to be focused on. A long-term sustainable use of forest natural resources also has to include measures to recreate biodiversity in biologically depleted areas. Methods of ecological engineering should be stimulated to reach these goals.

Projections of the Possible Effects of Global Warming on Boreal Forests in Alaska, Minnesota, and Siberia

Robert Nisbet
University of California, Santa Barbara, California, USA

The effects of global warming on forests during the next 70 years were compared for representative species on sites in Minnesota, Alaska, and Siberia. Although the last major episode of natural climatic change (the "little Ice Age") had many pronounced effects on travel, exploration, immigration, and crop production, there is no indication of its occurrence in the pollen records left by forests. Thus, we did not expect to see a large response of forests to the projections of climate change due to global warming.

Results for Minnesota contradicted this expectation and showed a rapid and strong response of the boreal forest of Minnesota to global warming; jack pine (*Pinus banksiana* Lamb.) declined and eastern white pine (*P. strobus* L.) increased in biomass under global warming conditions. Unlike Minnesota, eastern Siberia showed no significant changes in its larch forests during the next 70 years of global warming. Although black spruce (*Picea mariana* (Mill.) B.S.P.) and white birch (*Betula papyrifera* Marsh.) forests declined in Alaska at low elevations and white birch increased at high elevations, changes were less than in Minnesota.

Our research reveals that responses to global warming are site and species specific. An atlas of forest responses, with projections for many sites and many site conditions, would be useful to determine the overall effect of global warming on our forests.

A Proposed Forest Health Monitoring Database for Use in Boreal Forests

Vernon J. LaBau
USDA Forest Service, Pacific Northwest Research Station, Portland, Oregon, USA

The monitoring of the boreal forests of the world is a very important management dynamic in establishing a critical aspect of the initial baseline and ongoing databases needed to evaluate possible impacts of climate change and atmospheric pollution on forest ecosystems of the world's northern hemisphere. Such studies are especially important at the northern and upper limits of tree growth. This paper presents an overview of procedures used in the current Forest Health Monitoring Program in the United States and suggests how those studies will probably be extended to monitoring Alaska's boreal forest in the next few years. A plan for a world-wide network for monitoring boreal forests is presented, including suggestions as to which "indicators" might be most important to include in such an international study.

Boreal Forest Status and Research in Finland

Eino Malkonen
The Finnish Forest Research Institute, Department of Forest Ecology, Vantaa, Finland

Seppo Kellomaki
University of Joensuu, Department of Forestry, Joensuu, Finland

Finland has boreal coniferous forests from its southern border to the northern timber line. The development and growth of thesess forests have been systematically monitored since 1921–1923, when the world's first national forest inventory was carried out in Finland. Forest area is 23 million ha, which is about 75% of the land area of Finland. The variety of tree species is limited but all the main species—Scots pine (*Pinus sylvestris* L.), Norway spruce (*Picea abies* (L.) Karst.), and birch (*Betula* spp.)—are valuable for forest industry. The present growing stock, 880 million m^3, is the highest figure ever recorded. The estimate of annual growth is 80 million m^3, and the corresponding figure for cutting is 55 million m^3.

Forest condition surveying has been carried out annually since 1986 on the sample plot network of the eighth National Forest Inventory. The estimates of forest condition are based on the standardized methods of the UN-ECE program. The condition of forests as a whole is satisfactory, but forests in southern Finland are stressed by air pollution.

About one-third of Finland's forests are on peatlands. The amount of forest land in which utilization is restricted is 8% of the total forest area of the country. Nearly 25% of Lapland has been given wilderness areas status. The northern limit of the coniferous forest zone in Lapland has to be prevented from receding. Therefore, in upland areas only intermediate cuttings and natural regeneration are allowed.

The forest industry is the most important industrial sector in Finland. Forests products account for 40% the value of Finnish exports. The economic value of forests for recreation, reindeer husbandry, and mushroom- and berry-picking may be about 10% of its value for timber production.

Forest research receives about 5% of the state research budget. The funds used for forest research represent 1.2% of the manufacturing value of forestry. The most important topics in forest research are as follows:

- Effects of climate change and air pollution on forests
- The development of updated database describing the state of forests
- Formulation of models describing the development of forest
- Ecological bases of forest managemen
- The linkage between the different uses of forest and the protection and conservation of forest nature.

System of Forest Inventory and Monitoring in Russia

V.V. Nefediev
LESPROJECT, Moscow, Russia

Ground and remote methods of forest inventory with the use of aerophotographs and space images are described, as are a number of remote sensing technologies that can be used to monitor boreal forests. Data about forest resources and their state in Russia are presented.

Monitoring Long-Term Forest Succession With Synthetic Aperture Radar in the Taiga of Interior Alaska

Phyllis C. Adams, Leslie A. Viereck, Jobea Way, and Cynthia L. Williams
USDA Forest Service, Institute of Northern Forestry, Fairbanks, Alaska, USA

Synthetic aperture radar (SAR) has potential for monitoring successional dynamics by providing information about biophysical properties of vegetation, including biomass, canopy moisture content, canopy geometry, and phenologic changes. At Bonanza Creek Experimental Forest near Fairbanks, Alaska, images from aircraft missions in March 1988 and May 1991 have clearly demonstrated the capability of SAR to monitor environmental conditions such as snow cover, frozen and thawed ground and vegetation, river ice, and flooding. We have conducted extensive monitoring of structural characteristics and environmental parameters of successional stands along the Tanana River as ground truth for ERS-1 spaceborne and NASA AIRSAR aircraft missions. Stand density, biomass, species composition, and spatial and temporal patterns have been analyzed and will be examined for relationships to radar backscatter signatures. This work contributes to the development and calibration of mechanistic ecosystem models that attempt to predict ecosystem response to changes.

Environmental Monitoring of the Bonanza Creek Experimental Forest LTER Site

Leslie A. Viereck, Phyllis C. Adams, Joanna E. Roth, and Linda J. Patton
USDA Forest Service, Institute of Northern Forestry, Fairbanks, Alaska, USA

In the fall of 1987, the Bonanza Creek Experimental Forest joined the network of Long-Term Ecological Research (LTER) sites, and two permanent weather stations were established one on the floodplain of the Tanana River at 120 m elevation and the other on a broad ridge midway in a elevational transect of the experimental forest at 290 m locations representing the two major topographical subdivisions of the forest. In addition, selected environmental parameters are monitored at eight study sites, one in each successional stage represented by the LTER study.

Analysis of long-term climate records from the Fairbanks International Airport indicate increasingly warmer temperatures, especially since the late 1960's. The two Bonanza Creek weather stations may be useful in determining the significance of these data and the impact of the Fairbanks "heat island."

Soil temperatures are monitored at each study site. Although air temperatures do not vary greatly among stand types, soil temperatures show significant differences that can be correlated with forest productivity. Soil temperatures also indicate conditions favorable for the development of permafrost in some of the mature spruce stands. Depth of seasonal frost is measured weekly at each site during the summer.

The Bonanza Creek Long-Term Ecological Research Program

Leslie A. Viereck
USDA Forest Service, Institute of Northern Forestry, Fairbanks, Alaska, USA

K. Van Cleve
University of Alaska, School of Agriculture and Land Resources Management, Fairbanks, Alaska, USA

The Long-Term Ecological Research (LTER) program is supported by the National Science Foundation (NSF). The LTER program was developed by NSF to provide a coordinated network of sites on which long-term ecological experiments and monitoring could be carried out. In addition to monitoring, each site is encouraged to address research efforts in five core areas: (1) pattern and control of primary production, (2) spatial and temporal distribution of populations selected to represent trophic structure, (3) pattern and control or organic matter accumulation in surface layers and sediments, (4) pattern of inorganic inputs and movements of nutrients

through soils, groundwater, and surface water, and (5) pattern and frequency of distribution to the research site. There are presently 18 LTER sites that have been developed into a coordinated research program with a network office in Seattle, Washington.

The Bonanza Creek Experimental Forestry (BCEF) LTER site is operated jointly by the Institute of Northern Forestry and the University of Alaska at Fairbanks. The studies at the BCEF LTER site deal with successional processes in floodplain (primary) succession following alluvial deposition and in upland (secondary) succession following wildfire. The research is examining the premise that the pattern of succession is determined primarily by the initial soil and physical and chemical environment of the site and by the life history traits of component species, and that the rate of successional change is determined by vegetation-caused changes in environment and ecosystem function. Through a set of four corollary hypotheses, research is designed to test the central question focusing on important controls of ecosystem structure and function at major turning points in the successional sequences. A series of studies of various stages of succession are being used to monitor vegetation and environmental changes with succession and to serve as sites for experiments testing the four hypotheses.

Forest Succession on the Floodplain of the Tanana River in Interior Alaska

Leslie A. Viereck, Joan M. Foote, Phyllis A. Adams, and Joanna E. Roth
USDA Forest Service, Institute of Northern Forestry, Fairbanks, Alaska, USA

Vegetation of 12 stages of forest succession on the floodplain of the Tanana River is described. Succession on newly deposited alluvium begins with the invasion of willows (*Salix* spp.) and develops through a willow–alder (*Alnus tenuifolia* Nutt.) stage to forest stands of balsam poplar (*Populus balsamifera* L.), followed by white spruce (*Picea mariana* (Mill.) B.S.P.). During the successional sequence there is a gradual increase in terrace height, the development of a forest floor of leaf litter and mosses, and finally the development of permafrost. There is a general progression of plant species resulting from the modification of the environment by the developing vegetation. Life history and stochastic events are important in the early stages of succession, but biological controls become more important in the later stages of succession.

Papers Presented at the Third Annual Meeting of the International Boreal Forest Research Association

September 26—October 2, 1993
Biri, Norway, and Umea, Sweden

A "Model Forest Model": Steps Toward Detailed Carbon Budget Assessments of Boreal Forest Ecoystems

David T. Price and Michael J. Apps
Natural Resources Canada, Northern Forestry Centre, Edmonton, Alberta, Canada

Werner A. Kurz
ESSA Ltd., Vancouver, British Columbia, Canada

Michael Westbrook
Parks Canada, Jasper, Alberta, Canada

R. Sean Curry
Weldwood of Canada Ltd., Hinton, Alberta, Canada

The Foothills Forest, located in west-central Alberta, is one of ten "model forests" established under a Canadian federal government initiative to promote sustainable development and integrated management of Canada's forest resources. The Carbon Budget Model of the Canadian Forest Sector, developed collaboratively by the Canadian Forest Service and ESSA Ltd. (Kurz et al. 1992, Apps and Kurz 1991), is being modified to allow its use of local forest inventory data, other information on local ecosystem carbon, and industrial use of fossil energy, to permit a comprehensive assessment of the current carbon budget of the Foothills Forest. The model estimates pools of carbon stored in the forest (i.e., in vegetation, soils, and wetlands) and in harvested products that have left the Weldwood mills since they began operations in 1957. In addition, it examines the net annual changes in these pools due to forest growth, ecosystem disturbances, harvesting and silvicultural treatments, and decomposition (both in the forest and of forest products in buildings and landfills elsewhere in the world). The model also has the facility to assess biofuel consumption and to offset this against fossil fuel CO_2 *emissions from forest operations. The assessment requires the compilation and analysis of all available data on forest growth and yield, ecosystem classification, soils, losses due to fires and insect attack, and historical data on harvesting and wood processing.*

The anticipated end-product will be a detailed carbon budget analysis for the Foothills Forest for a single representative year (tentatively 1988), broken down by land area classifications such as ecosystem types and management working circles. The implications of prescribed scenarios for changes in management or climate (e.g., in terms of increased harvesting levels or increased fire losses) can then be investigated as a means of exploring possibilities for improved adaptive management for all Canadian boreal forest ecosystems.

Introduction

Canada is the custodian of 10% of the world's forested area, of which about 75% is classified as **boreal** under the current climatic conditions. These forests have become a focus of public interest in recent years, both locally and internationally. Within Canada, the environmental impacts of logging and loss of mature forest habitats are major perceived causes of concern. In addition, recent scientific developments have suggested that achieving a balance of the global carbon budget may be very dependent upon the existence of a northern terrestrial carbon sink (Tans et al. 1990, D'Arrigo et al. 1987). Particular attention has been focused on the circumpolar boreal forests because they are known to contain very large reservoirs of carbon (C), not merely in biomass, but to a greater extent in soils and peatlands. With global climate warming over the next 50 to 100 years increasingly seen as a probability, there are additional fears that the carbon contained in mid-latitude forest ecosystems will begin to be released. Carbon will be released as wetlands dry out, decomposition of soil organic matter accelerates, and forest fires and mortality due to insects and other pests increase.

The ultimate impacts of a changing climate on these boreal ecosystems could be of considerable socioeconomic significance, and it is therefore of timely importance to investigate their current and possible future roles as sinks, or sources, of atmospheric CO_2. In fact, forest carbon budgets are beginning to be regarded as important indicators of ecosystem "health" (because net CO_2 sequestration within the system is closely related to net ecosystem productivity), while there is increasing interest in the management of forests as a means of offsetting carbon emissions from fossil fuel consumption. To quantify the role of boreal forests as carbon sinks, it is important to be able to precisely assess the current carbon balance and the impacts thereon of forest management, including harvesting and wood processing.

Several large-scale forest-sector carbon budget assessments have been attempted recently for northern temperate and boreal forests (e.g., Apps et al. 1993b, Apps and Kurz 1991, Kauppi et al. 1992, Vinson and Kolchugina 1993, Sedjo 1992). In general, these carbon budget assessments are based on data and algorithms that may represent a good compromise between computing limitations and data availability but will inevitably leave some uncertainty in the final estimates. One might ask: Is it possible to determine how large this uncertainty could be? Using such models to assess the carbon budgets of smaller regions, for which detailed information is available, enables the evaluation of factors for which there are inadequate data at the national scale. Such examination can both provide a measure of confidence for the larger scale analyses and help guide further improvements to national-scale and global-scale models.

There is a second question, which is strongly connected to the first: Can future large-scale carbon budgets be estimated successfully using process-based ecosystem level models? (Price and Apps 1993, Price et al. 1993). This is an important question because any attempt to use results from a number of point-based simulations derived from process-based models to provide an integrated estimate of the regional carbon budget is normally very difficult to validate. Development of a carbon budget for an entire forest unit using a modified version of the Carbon Budget Model of the Canadian Forest Sector (CBM-CFS) can provide a comprehensive assessment against which scaled-up estimates derived

from smaller scale models may be compared.

This paper outlines current work aimed at determining the carbon budget for the area of the Foothills Forest, a "model forest" located in the boreal region of western Alberta. The end-product should provide local forest managers with some of the information they will need to deal with potentially serious future economic and ecological problems. At the same time, the development of this assessment is expected to contribute to an ongoing validation of both national-scale assessments and smaller scale models while providing enhanced scientific insight into the challenging problems of spatial and temporal scaling.

Carbon Budget Model

The CBM-CFS was developed collaboratively by the Canadian Forest Service and ESSA Ltd. The model's structure and operation have been extensively documented in recent papers by Apps and Kurz and their co-workers (e.g., Kurz et al. 1992, Apps and Kurz 1991, Apps et al. 1993). Briefly, CBM-CFS is a large-scale prognostic model that tracks the major pools and fluxes of carbon within Canadian forest ecosystems, and estimates the net carbon uptake from the global atmosphere. Using data on forest growth, soil processes, ecosystem disturbances, and human activity (harvesting and wood use), the model has been used to estimate historical, current, and future carbon budget assessments for Canadian forests. Each assessment is reported as an "annual balance sheet" of the carbon budget under prescribed conditions and within a specified forested region. The current model (CBM-CFS 2) assesses the national forest sector carbon budget based on 42 spatial units covering the whole of Canada (nearly 10 million km^2, of which about 4.5 million km^2 have some form of tree cover).

The objective of the present study is to modify CBM-CFS 2, and use it to derive more precise estimates of the carbon budget for smaller forest management units such as the Foothills Forest. The modified model should be generally applicable to other forested regions where suitable data are available. It will be used to calculate carbon accumulation and losses associated with locally determined rates of forest growth and decomposition, combined with local disturbance records. The assessment will include estimates of the inventory of carbon within the forest area, classified as identifiable pools including: merchantable and non-merchantable forest biomass, forest soils, and wetlands; and estimates of net annual gains and losses in these pools due to local ecosystem dynamics and management prescriptions. In addition, precise estimates will be made of the carbon exported from the forest and converted to sawn timber and other wood products. The net accumulation of carbon in wood products from the forest during its operational history will be estimated, with different rates of decay applied to each group of products. The modified CBM-CFS will also be used to account for carbon released from wood-waste oxidized to generate energy, which will be segregated from carbon emissions from fossil fuels consumed in forest operations. Hence, a complete carbon budget assessment will be obtained to provide answers to key questions concerning the possible impacts of forest management, disturbances and harvesting on the forest carbon balance. For example: Is the forest a net sink, or source of atmospheric CO_2? What are the likely impacts of management and/or changes in disturbance regime (such as changes in fire frequency due to climate warming) on the net CO_2 sink/source?

The Foothills Forest

The Model Forest Network was initiated by the Canadian federal government as part of its Partners in Sustainable Development of Forests Program. The stated objectives are firstly, to accelerate the implementation of sustainable development in forestry practice, particularly the concept of integrated resource management; secondly, to develop and apply new and innovative concepts and techniques in forest management; and thirdly, to test and demonstrate the best sustainable forestry practices available (Forestry Canada 1993). Ten model forests have now been established at sites representative of the five major forest ecoregions of Canada (figure 1).

The 1.2-million-ha Foothills Forest is located in west-central Alberta, immediately east of Jasper National Park and the Rocky Mountains (figure 1). It is sponsored jointly by Weldwood of Canada Ltd., which operates the forest management agreement (FMA) area and wood-processing facilities based in the town of Hinton, the Alberta provincial government, the Alberta Forest Technology School in Hinton, and the Canadian Forest Service. In addition to these sponsors, there are over 70 partners in the Foothills Forest, including municipal and other provincial and federal government agencies, educational institutions, professional associations, unions, small businesses, consultants, and environmental interest groups.

The local topography features rolling hills and ridges, with an elevational gradient ranging from about 900 m at the eastern boundary of the FMA to about 1,800 m at

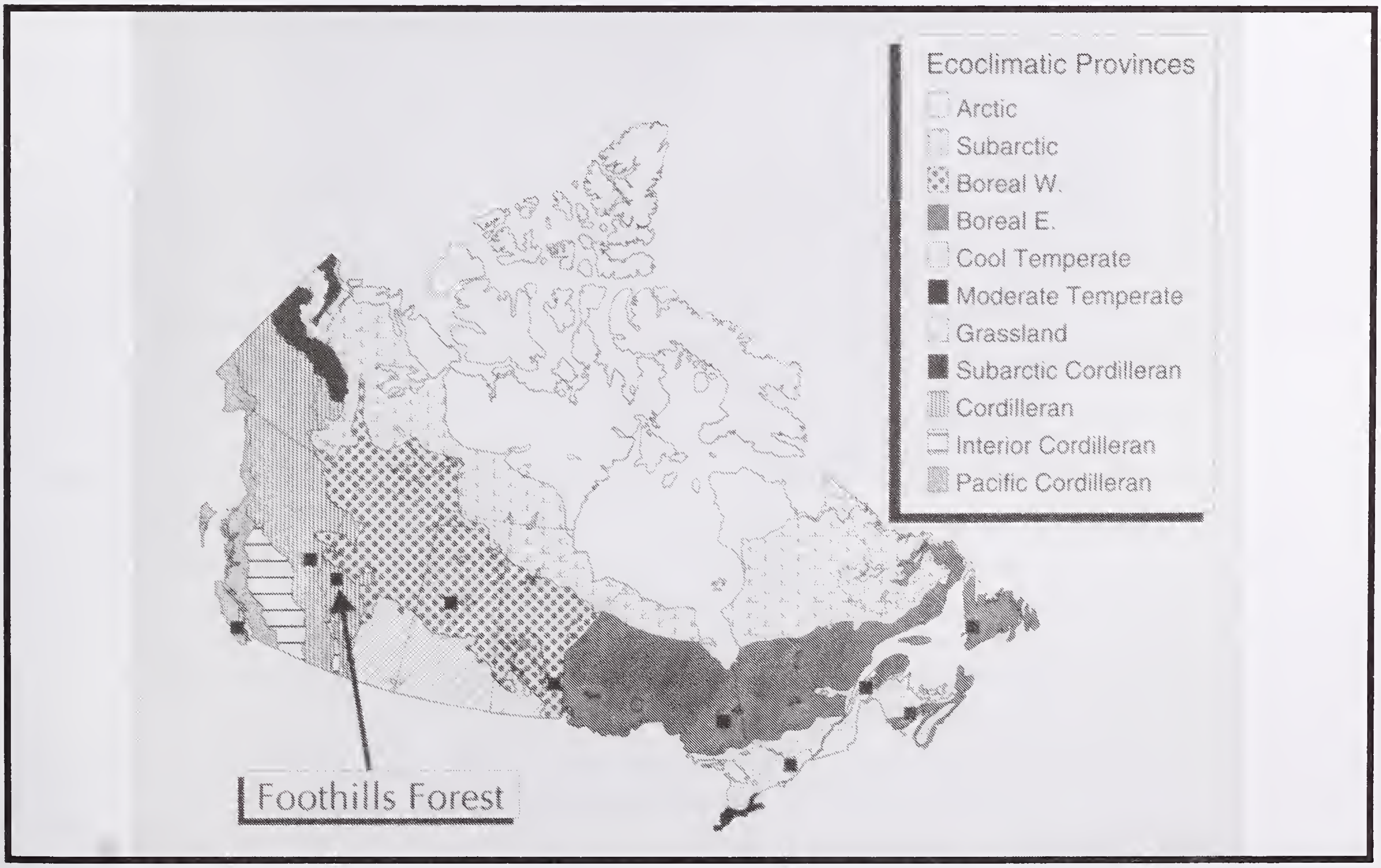

Figure 1—Map of Canada showing the Canadian ecoclimate provinces (from Ecoregions Working Group 1989) and approximate locations of the ten model forest sites (from Forestry Canada 1993).

the western edge bordering the mountains. Figure 2 shows that the Foothills Forest area lies mainly in the Upper and Lower Boreal-Cordilleran ecoregions, with small areas extending into the Subalpine and Montane ecoregions (Alberta Forestry, Lands and Wildlife 1992). Well-drained mineral soils (gray luvisols) are most common, and the coniferous forest is composed mainly of dry-site species, lodgepole pine (*Pinus contorta* Dougl. ex. Loud.) being predominant. This is true particularly of the Upper Boreal-Cordilleran and Montane ecoregions, though extensive areas of spruce-dominated forest are typically found in low-lying wet areas, which occur more frequently in the Lower Boreal-Cordilleran. With the exception of jack pine (*P. banksiana* Lamb.), all the tree species typically found in the western Canadian boreal forest can be found within the Foothills Forest. The Boreal-Cordilleran ecoregions are otherwise broadly similar to the Southern Boreal forest ecoregions differing only in that in the absence of fire, the natural succession usually proceeds to

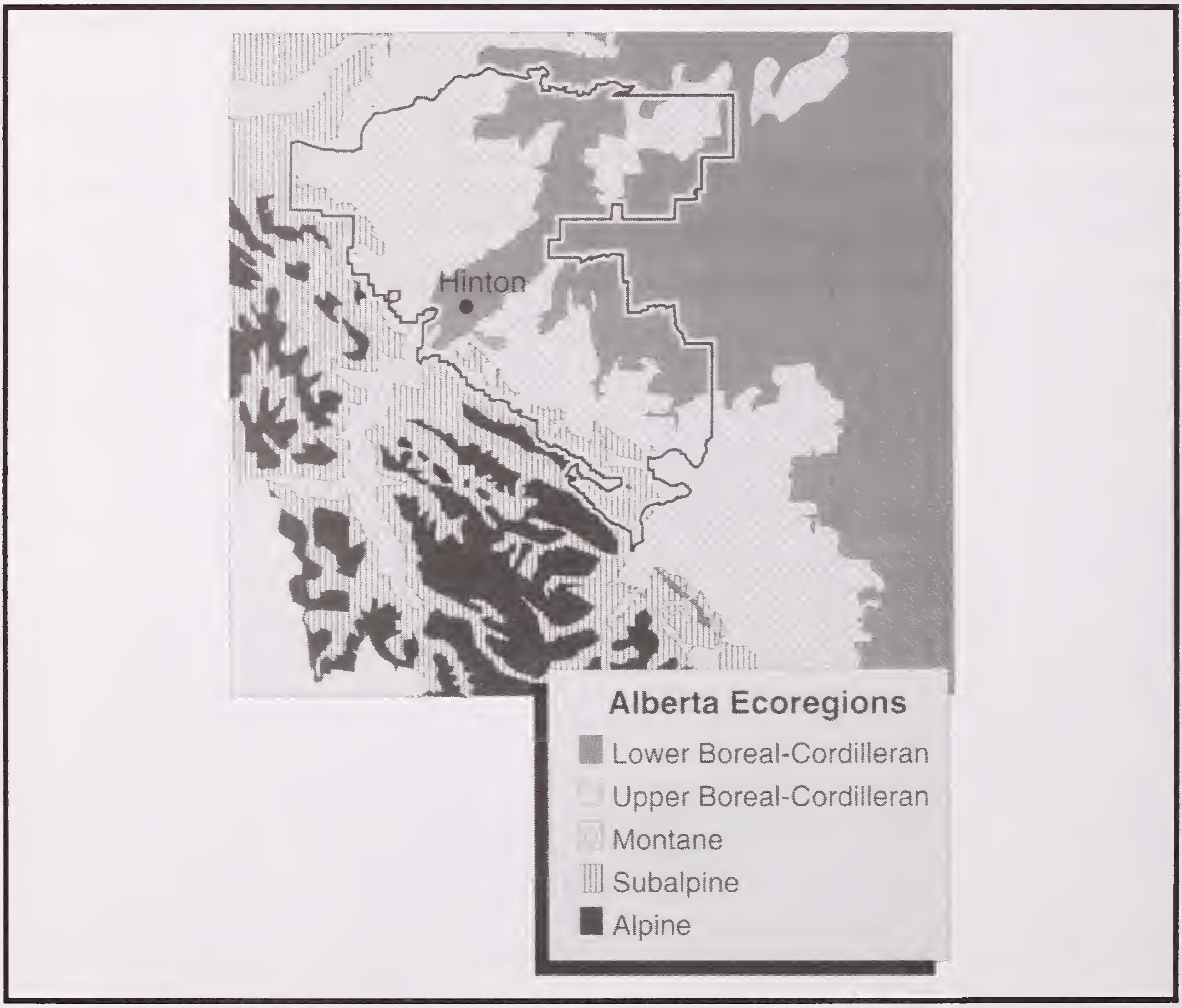

Figure 2—Map showing approximate location of the Foothills Forest boundary, superimposed on the loca ecoregions (from Alberta Forestry, Lands and Wildlife 1992).

mixtures of white and black spruce (*Picea glauca* (Moench) Voss and *P. mariana* (Mill.) B.S.P.) with balsam fir (*Abies balsamea* (L.) Mill.) rather than to pure *P. glauca* or a *P. glauca / A. balsamea* mixed wood (Alberta Forestry, Lands and Wildlife 1992). Local soils and ecosystem data have been obtained recently for the neighboring Jasper National Park by the Canadian Parks Service, and additional data will be collected from similar field studies in the Foothills Forest area.

Weldwood of Canada is the most recent of several forest management companies that have operated the FMA continuously since 1954, a period during which a high standard of forest management has been introduced and maintained. The total area of the Foothills Forest is 1,218,014 ha; this consists of the Weldwood Forest Management Area, which totals 1,012,119 ha (comprising 210,549 ha of inoperable area and 801,570 ha of operable area), plus the Alberta Government Area, which contains 205,895 ha. The FMA area is further subdivided into five working circles, each considered to be a sustained yield management unit. During the late 1950's, systematic coverage of about 3,000 permanent growth sample plots (PSP's) was begun. Data collected from these PSP's are used to determine differences between actual and projected stand growth rates and hence update periodic estimates of the annual allowable cut (AA). The sustained yield harvest from the entire FMA area is currently estimated to be about 2.0 million m^3/yr, 95% of which is coniferous (Weldwood of Canada Ltd. 1992).

In addition, good data are available since operations began in 1956 of harvesting yields and the processing of harvested material through the mills. The bleached kraft pulpmill has a current capacity of 385,000 t/yr, whereas the stud mill can process 195,000 m^3/yr. Sawmill residues are either transferred to the pulpmill, or used as bioenergy sources. About 50% of the pulpmill's chip requirements are met from the FMA, with the balance purchased from other sawmills in neighboring districts.

The CBM-CFS allows for the possible use of forest products as energy sources and tracks the associated releases of carbon. Currently, about 74% of Weldwood's energy supply comes from wood products (17% hog fuel and 57% black liquor), with the balance coming from natural gas (25%) and diesel fuel (1%). The Foothills Forest area contains significant reserves of coal and natural gas, many of which are currently being exploited. Releases of carbon associated with the production and utilization of these fossil fuels (other than by the forest sector itself) will not be included in the forest sector carbon budget. For ecosystem processes, only changes in organic carbon deposited within the soil profile through decomposition of plants that have established in the area since the last glaciation (more than 10,000 years ago) are considered in the CBM-CFS; over the time scales of interest (~100 years), geological formations of fossil carbon reserves are considered stable and therefore ignored.

Data Requirements

The carbon budget assessment requires compilation and analysis of a range of available data on forest growth and yield, ecosystem classification, soils, and historical data on disturbances (including forest harvesting and fires), as well as information on management practices. The use of Weldwood's operational records on inventories, harvesting yields, mill wood consumption, and product out-turn, will provide a more accurate assessment.

In its current configuration, CBM-CFS provides carbon budget information broken down by areal groupings classified according to criteria that may be derived directly from geographic information systems (GIS). The information required for classifying forested areas includes species mix (softwood/hardwood), stocking density, site productivity, age class, land use (i.e., harvestable or "non-productive"), and stand origin (by disturbance type, if known). The Foothills Forest stand inventory data are maintained within a GIS, but some modifications or pre-processing will be required to enable CBM-CFS to operate on these data. The Foothills Forest database provides information on the breakdown of the area into non-forested and forested areas, and the division of the latter into operable and inoperable areas. For the carbon budget assessment, precise geographic location of individual stands is not needed; consequently, all records for similar stand types can be merged to greatly reduce the database used in the CBM-CFS calculations. There are over 300,000 records in the Foothills Forest inventory database; these were aggregated into approximately 5,000 stand-level records to provide a stand-type classification based on criteria including primary and secondary species, canopy density, site index, year of stand origin, and total area. A summary of the 5-year age-class distribution of area within the FMA is shown in figure 3.

Growth and yield data derived from the PSP's have been used to generate approximately 70 volume-yield curves (YC's), which are considered to represent the entire range of growing stock conditions within the FMA. The stands identified in each inventory record can then be matched to one YC (which actually provides separate yield curves for the softwood and hardwood components), from which standing volume may be estimated as a function of age. At the Canadian national scale, however, PSP's have typically not been installed in low productivity forests of little or no commercial potential, so yield curves are not generally available for all forest types. Consequently, direct data for forest biomass growth rates were not available at

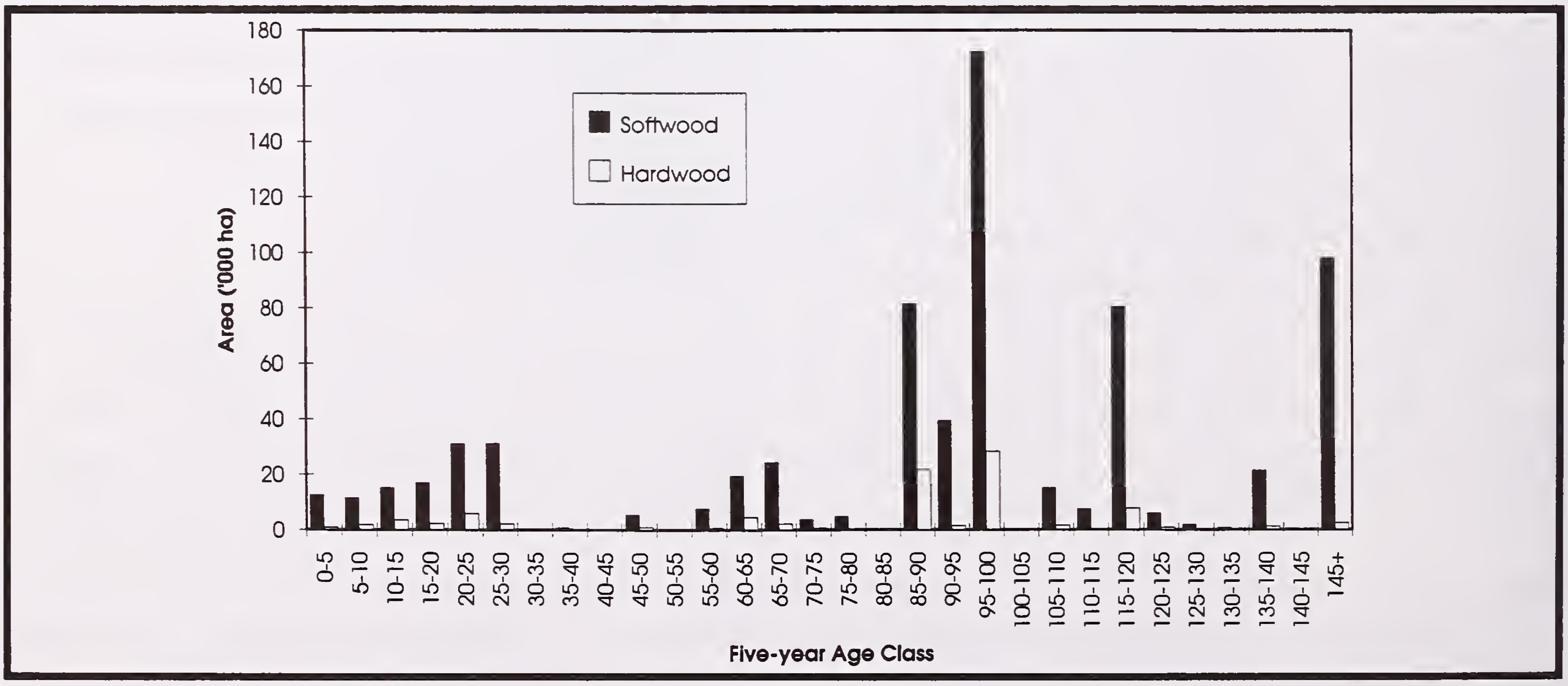

Figure 3—Age-class structure of the Foothills Forest Forest Management Area, based on data obtained for the 1988 forest inventory (Weldwood of Canada 1992).

a national scale, presenting a challenge for the assessment of the national forest carbon budget. To overcome this limitation, Kurz et al. (1992) used biomass inventory data collected by Bonnor (1985) to develop approximate relationships between stand age and measured biomass (referred to as "biomass over age" curves) for a suite of 457 ecosystem types. These curves were then used to estimate stand growth rates following annual disturbances for different ecoregions within the entire country.

The Foothills Forest study provides an opportunity to examine inaccuracies resulting from the CBM-CFS approach. Two sets of biomass-over-age curves can be derived from the stand inventory data (for ecosystems in the local boreal and cordilleran ecoregions) by using the present CBM-CFS methods and, independently, from Weldwood's PSP volume yield data. Comparison of the carbon budget estimates using these two sets of curves should be a direct indication of the inaccuracies of the CBM-CFS approach and should also indicate the sensitivity of larger-scale carbon budget assessments to uncertainties in these relationships.

Alternatively, because the CBM-CFS is sufficiently flexible to allow the insertion of a new biomass growth module based on Weldwood's volume yield curve calculations, the accuracy of short-term projections of biomass growth could be improved for regional estimations. Such an approach would be valid only if future environmental conditions are assumed to be similar to those under which the PSP data were obtained and would generally require modification in a changing climate. Whether the CBM-CFS inventory or the volume YC approach is used, merchantable timber volumes can be conveniently converted to estimates of total above-ground biomass, e.g., using species-specific empirical equations such as those derived by Singh (1984), while carbon content is taken to be 50% of dry mass. Estimation of the below-ground biomass component is, however, notoriously difficult. Based on the few available data, Kurz and Apps (unpublished manuscript) have established preliminary regression equations for predicting the ratios of above-ground to below-ground biomass for Canadian softwood and hardwood trees.

Soil survey data, including humidified depths and carbon density, are also needed to assess the distribution and hence total carbon storage in the soils of the Foothills Forest, in combination with existing GIS polygons. Representative data are currently available for approximately 15 sites within or close to the Foothills Forest area. Survey data on accumulations of litter, snags, and fallen trees are also required. Wetland areas will be assessed separately, but if found to be a significant component of the FMA, may require extra field data collection to determine their average net rates of carbon accumulation.

Records of past forest fires and insect attacks will be assessed to determine the average frequency of such events and their impacts on growth rates. Within the Foothills Forest, however, fires and insect outbreaks have been infrequent over the last 35 years, and their effects on timber yield projections are not considered to have been significant to date. A fire-origin map showing the distribution and ages of forest stands was constructed in 1961 and subsequently updated in 1988. This age-structure information will enable the frequency of fires to be estimated in the forest before it was brought under management (e.g., Van Wagner 1978).

For the national-scale carbon budget assessment, Kurz et al. (1992) developed

"carbon retention curves" to represent the average decay rates of different groups of forest products. These curves were then used to estimate the contributions to the contemporary forest product carbon pool of wood products manufactured within the previous 40 years. The same curves will be applied to Weldwood's products, based on the assumption that for any particular tree species, the geographic origin of forest products manufactured within Canada does not have any significant impact on their average life span. Historical records of annual sales, classified by product type (and tree species if available) will be needed in combination with the carbon retention curves, to estimate the total carbon currently retained in forest products extracted from the FMA in all years prior to and including the year of assessment.

For any given year, the difference between the inventoried timber volume on a harvesting site and the volume of timber extracted to road-side, can be used to estimate the annual transfers of biomass carbon to the forest soil carbon pool due to harvesting. Similarly, the difference between the mass of timber extracted and the sum of the masses of sawn timber and pulp and paper products sold by the mills can be used to estimate the quantity of wood waste produced during processing. The ultimate fate of this wood waste will be tracked in order to determine possible further additions to the soil, dumping in landfills, direct releases to the atmosphere, fluid effluent discharges, and substitution for fossil energy.

Data on annual fossil fuel consumption by the forest industry are needed, because the CO_2 released can be balanced against the net uptake of carbon by the forested area. Classification by operation (e.g., harvesting, transport to mill, milling, silviculture, administration) is not strictly necessary for the carbon budget assessment but could be of managerial importance if carbon emission controls were to be implemented. Information on electricity consumption (and its fossil fuel equivalence) would also be useful, though in the case of Weldwood's operation this appears to be an insignificant energy source, compared to consumption of organic fuels and bioenergy. Given that some wood chips processed by the pulpmill are imported from other mills not supplied by the FMA, it will be necessary to make appropriate reductions when estimating the energy consumed, and waste material produced, in processing them.

End Products

The model will be used initially to generate a detailed carbon budget analysis of the Foothills Forest area for a single representative year (probably 1988, the date of the most recent forest inventory). The output will be presented as a balance sheet detailing carbon storage and fluxes among the identifiable carbon pools, including the current rates of atmospheric carbon uptake in forest growth, releases due to decomposition, and transfers from vegetation to soils and wood products due to harvesting and other ecosystem disturbances. The budget will be presented for the entire forest area and broken down on the basis of land area classifications including the local ecoregions and management working circles.

The sensitivity of the Foothills Forest carbon budget to prescribed disturbance scenarios will also be investigated by comparing the results with those obtained for the 1988 reference year (e.g., effects of increases in the areas annually harvested, burned or subjected to insect attack). These sensitivity tests will provide indications of the likely responses of the Foothills Forest annual carbon balance to possible future changes in climate and/or management

regime. The model will then be used to generate retrospective time series data (e.g., carbon budget assessments at 5-year intervals under known past conditions of climate, disturbances, and management), as a means of validating the model against the observed record of forest carbon dynamics. Finally, it will be used to project into the future to more fully investigate the possible long-term (50 to 100 years hence) responses of cumulative changes in climate and management. Specific questions to be addressed include

1. What are the possible impacts of changes in climate (operating via effects on growth and disturbance regimes) on current net CO_2 uptake and on the sustained yield harvest, within the Foothills Forest?
2. What impact might alternative management scenarios and/or government policies have on the carbon budget of the Foothills Forest?
3. How might local management be altered to minimize climate change impacts?

Discussion

It was previously stated that the Foothills Forest carbon budget study will provide an opportunity to verify regional- and national-scale carbon budget assessments made using the existing national-scale CBM-CFS. In principle, the carbon pools and fluxes (expressed on a unit area basis) obtained for an entire spatial unit using regionally averaged data can be compared with those estimated for the FMA area using the same carbon accounting framework but operating on the more detailed and localized data bases. In practice, however, such a comparison is not without problems.

Firstly, close agreement between these estimates is generally unlikely, because the attributes of the smaller area, such as average site productivity, can be expected to differ from the average values used for the large-scale estimate. In the case of a forest management unit, this is quite probable if only because forest managers will tend to favor areas of higher than average productivity for their operations. Secondly, there is also the possibility that the conceptual framework used in the CBM-CFS is incomplete or otherwise inadequate to account for the complete carbon budget at the smaller scale of the forest management unit. The problem in this case will be in distinguishing real differences in the average carbon budget from those attributable to possible errors or omissions in the model framework.

Running the model at the smaller scale may not expose such weaknesses directly, but it will provide a better opportunity for comparisons with independent data derived from other sources. For example, estimates of volume increment derived from regional forest inventory statistics may be compared with local estimates of increment derived from Weldwood's volume growth models applied to the forest inventory data. At a minimum, such comparisons will provide an indication of the errors inherent in the estimation of biomass carbon fluxes at the scale of the spatial unit, and provide guidance for improving the national-scale estimate.

In addition to the procedures outlined above, it will be possible to simulate forest dynamics for the Foothills Forest using a large-scale ecosystem model. Given past climate data and locally determined soil characteristics, plus information on the breakdown of site types (using digital terrain maps if possible), it is planned to run a modified version of the FORSKA 2 gap-phase dynamics model (Prentice et al. 1993) for the area of the Foothills Forest.

The test will be to determine whether FORSKA 2 can successfully approximate the structure of the current forest (i.e., species composition, biomass distribution, and age class structure). This will be an ambitious test, but a comparison between CBM-CFS and FORSKA 2 applied to the area of a 1,000-km transect extending across the boreal forest regions of Saskatchewan and Manitoba, has already yielded encouraging results (Price et al. 1993). Simulating the ecosystem processes in the area of the Foothills Forest will be considerably richer in detail, because complete detailed information on stand inventory and growth rates is available for comparison with model output. Furthermore, the significant elevational differences occurring across the area of the Foothills Forest will almost certainly require consideration of elevational impacts on climate, comparable to the latitudinal effects being investigated in the case of the boreal forest transect. If the ecosystem model can be used successfully to predict the contemporary carbon budget, based only on recent climate data and the local disturbance history, then an important step will have been achieved in the development of a process-based model for assessing large-scale ecosystem responses to climate.

When suitably modified, CBM-CFS can be used to calculate the carbon budget of the Foothills Forest or of any other forest management unit for which data are available, under a range of prescribed scenarios. Responses of the forest carbon budget will be of importance in assessing possible ecological and socioeconomic consequences of changes in forest management practices, alternative harvesting methods and anticipated increases in ecosystem disturbances associated with a changing climate. Such information will clearly be of value to forest managers and policymakers alike, especially when working in the climate-sensitive boreal forest regions. As the environmental and economic concerns expressed by different interest groups become increasingly important in future forest management, the need for information to make decisions will grow significantly. The modified CBM-CFS can be used to assist long-term adaptive management (e.g., to respond to or mitigate the effects of climate change), but compiling the input data, running the model and interpreting its output requires scientific expertise.

In the longer term, it is anticipated that a suitably modified version of the CBM-CFS will be used as part of an ecologically based decision support system (DSS). Using local forest inventory and ecological classification data maintained within a GIS, changes in the future landscape (i.e., in vegetation distribution) would be forecasted for a range of possible future scenarios using suitably calibrated forest growth models and/or ecosystem models. These forecasts would be subject to the effects of different possible management options, and their potential consequences evaluated using a suite of environmental assessment models (EAM's), of which the carbon budget assessment would be one (others would include habitat supply analysis, timber yield projections, and watershed and recreational impact assessments). After evaluating the output from all of the EAM's, under each of the considered options, the management strategies could be refined and the cycle repeated until an acceptable strategy emerged. This iterative process of scenario-based forecasting, evaluation, and strategy refinement could be routinely updated by forest managers during management and policy decisionmaking. If implemented for other forest management units, it would also facilitate regional- and national-scale planning, where carbon budget interests could be balanced against other resource management considerations

at these larger scales.

Summary

The Foothills Forest carbon budget study promises to answer some important questions about the current carbon balance of a definable area of boreal forest and about the effects of human management activities as compared to its previous unmanaged state. With increasing concern being expressed about the possible impacts of climate change on boreal forest ecosystems, the study will also be able to assess some of the possible future impacts on net carbon uptake and projected timber yields within this area. There are at least two approaches to determining the carbon budget of the Foothills Forest: (1) downscaling the national-scale carbon budget model (CBM-CFS) and (2) upscaling from canopy and ecosystem scale models. If convergence can be achieved, there will be three important conclusions.

1. The uncertainties in the contemporary national-scale forest sector carbon budget assessment will be better defined.
2. Validation of process-based estimates of forest sector carbon budgets over large areas can lead the way to better projections of national-scale forest responses to possible future global change.
3. It will be possible to place forest-based management in context with larger-scale carbon budget assessments, i.e., to determine the relative importance of forest management actions on the national scale carbon budget.

The last of these is particularly important because it will assist in merging economic objectives with ecological values, a primary consideration in achieving sustainable resource management, and a primary objective of the Model Forest Program.

Acknowledgments

We thank Paul Galbraith, Superintendent of Jasper National Park, for his encouragement of this project and Parks Canada for its financial support. We are grateful to Hugh Lougheed for contributing his ideas on the development and implementation of an ecologically based decision support system. Steve Zoltai, Ian Campbell, and Chao Li in provided constructive criticisms of an earlier draft.

References

Alberta Forestry, Lands, and Wildlife. 1992. Ecoregions and Ecodistricts of Alberta, Volume 1. Edmonton, AB: Land Information Services Division, Resource Information Branch.

Apps MJ, Kurz WA. 1991. Assessing the role of Canadian forests and forest activities in the global carbon balance. World Resource Review 3(33): 3.

Apps MJ, Kurz WA, Luxmoore RJ, Nilsson LO, Sedjo RA, Schmidt R, Simpson LG, Vinson TS. 1993a. Boreal forests and tundra. Water, Air, and Soil Pollution 70: 39.

Apps MJ, Kurz WA, Price DT. 1993b. Estimating carbon budgets of Canadian forest ecosystems using a national scale model. In: Kolchugina T, Wilson TE, eds. Carbon cycling in boreal forests and subarctic ecosystems: biospheric responses and feedbacks to global climate change. Report EPA/600R-93/084. Washington, DC: U.S. Environmental Protection Agency, Office of Research and Development.

Bonnor GM. 1985. Inventory of Forest Biomass in Canada. Chalk River, ON: Canadian Forestry Service, Petawawa National Forest Institute.

D'Arrigo R, Jacoby GC, Fung IY. 1987. Boreal forests and atmosphere-biosphere exchange of carbon dioxide. Nature 329: 321.

Ecoregions Working Group, Committee on Ecological Land Classification. 1989. Ecoclimatic regions of Canada, first approximation. Ecological Land Classification Series No. 23. Ottawa, ON: Environment Canada, Canadian Wildlife Service, Sustainable Development Branch,

Conservation and Protection.

Forestry Canada. 1993. Canada's Model Forest Program: an initiative for sustainable development. Chalk River, ON: Forestry Canada Publications Distribution Centre, Petawawa National Forestry Institute.

Kauppi PE, Mielikainen K, Kuusela K. 1992. Biomass and carbon budget of European forests, 1971 to 1990. Science 256: 70.

Kurz WA, Apps MJ, Webb TM, McNamee PJ. 1992. The Carbon Budget of the Canadian Forest Sector: Phase 1. Northwest Region Information Report NOR-X-326. Edmonton, AB: Forestry Canada, Northern Forestry Centre.

Kurz WA, Apps MJ. 1994. Estimation of root biomass and dynamics for the Carbon Budget Model of the Canadian Forest Sector. (manuscript in preparation).

Prentice IC, Sykes MT, Cramer W. 1993. A simulation model for the transient effects of climate change on forest landscapes. Ecological Modeling 65: 51.

Price DT, Apps J. 1993. Integration of boreal ecosystem-process models within a prognostic carbon budget model for Canada. World Resource Review 5: 15.

Price DT, Apps MJ, Kurz WA, Prentice IC, Sykes MT. 1993. Simulating the carbon budget of the Canadian boreal forest using an integrated suite of process-based models. In: Ung C-H, ed. Forest Growth Models and Their Uses. Proceedings of an international workshop; November 18-19, 1993; Quebec City, PQ: 251-264.

Sedjo RA. 1992. Temperate forest ecosystems in the global carbon cycle. Ambio 21: 274.

Singh T. 1984. Conversion of tree volume to biomass in the prairie provinces. Forest Management Note 28. Edmonton, AB: Canadian Forestry Service, Northern Forest Research Centre.

Tans PP, Fung IY, Takahashi DT. 1990. Observational constraints on the global atmospheric CO_2 budget. Science 247:1431.

Van Wagner CE. 1978. Age-class distribution and the forest fire cycle. Canadian Journal of Forest Research 8: 220.

Vinson TS, Kolchugina TP. 1993. Pools and fluxes of biogenic carbon in the Former Soviet Union. Water, Air, and Soil Pollution. 70: 223.

Weldwood of Canada, Ltd. 1992. 1991 Detailed Forest Management Plan. Hinton, Canada: Forest Planning Group, Forest Resources Department.

Changing the Spruce (*Picea* spp.) Component in a Northern Conifer Forest Through an Array of Silvicultural Options

John C. Brissette and Robert M. Frank
USDA Forest Service, Northeastern Forest Experiment Station, Orono, Maine, USA

he effects of a number of silvicultural systems and reproduction methods on stand structure and tree growth are being studied in a long-term experiment on the Penobscot Experimental Forest in east-central Maine (lat. 44 52' N, 68 38' W). The area is in the Acadian Forest Region. The elevation is low (less than 75 m above sea level), the soils are of glacial origin and tend to be somewhat poorly to poorly drained, and the climate is cool and moist. The Penobscot Experimental Forest is predominately coniferous, with a mixture of spruces, mostly red (*Picea rubens* Sarg.) and white (*P. glauca* (Moench) Voss) with a few black spruce (*P. mariana* (Mill.) B.S.P.); balsam fir (*Abies balsamea* (L.) Mill.); eastern hemlock (*Tsuga canadensis* (L.) Carr.); northern white-cedar (*Thuja occidentalis* L.); eastern white pine (*Pinus strobus* L.); and some associated hardwoods, especially paper birch (*Betula papyrifera* Marsh.) and red maple (*Acer rubrum* L.).

One of the original objectives of the experiment was to determine the best silvicultural system or reproduction method for increasing the spruce component in northern conifer forests. Spruce is favored over its common associate balsam fir for both pulpwood and lumber products. Spruce is also less susceptible than balsam fir to the spruce budworm (*Choristoneura fumiferana* Clem.), a native defoliating insect that reaches epidemic levels about every 40 years.

In the experiment, even-age treatments include two- and three-stage shelterwood systems, and clearcut harvesting. Uneven-age treatments include fixed and flexible diameter limit methods, and selection with 5-, 10-, and 20-year harvest intervals. The experiment was established between 1952 and 1957 in stands with a history of logging but no recent activity. Each treatment is replicated twice in compartments averaging 10.1 ha in area. There is also an unmanaged control. Stand structure has been measured every 5 years on an average of 18 permanent plots (each 809 m in size) per compartment.

Treatments under study that develop even-aged stands originally contained 7 to 10% spruce trees. If the young stands were tended by cleaning and spacing when they were 2 to 3 m tall, the shelterwood system increased the spruce component, as measured in percentage of total trees, by 26%. Without tending, shelterwood produced no change in the percentage of spruce. Five years after a clearcut harvest, the spruce component was 4% less than it had been in the original stand.

In the uneven-aged stands under study, spruce accounted for 12 to 20% of the total basal area when the experiment was estab-

lished. After 35 years, the proportion of basal area that is spruce has not changed in the control. Under the fixed diameter limit method, which does not permit favoring individual trees, spruce representation declined 7%. The flexible diameter limit method, which does allow favoring individual trees, has increased spruce representation by 6%. Under the various selection harvest intervals, spruce representation has increased 9 to 18%.

Climate Change and Potential Forest Changes in Alaska

Gordon C. Jacoby and Roseanne D. D'Arrigo
Lamont-Doherty Gerological Observatory, Tree-Ring Laboratory, Palisades, New York, USA

Glen P. Juday
University of Alaska, Department of Forest Sciences, Fairbanks, Alaska, USA

Recorded temperature data and analysis of annual ring widths and maximum latewood density from old-aged trees in central and northern Alaska show that annual temperatures have warmed over the past century and that summer temperatures have also increased in the last few years. The longer tree-ring record indicates that the annual warming is unusual in the context of several centuries. The summer temperatures are warm but not that unusual except for 1993. These results and other data indicate also significant warming of fall, winter, and spring temperatures in agreement with GCM models.

Tree growth and forest response to the increased temperatures are varied. Positive effects are increases in growth rates and elevation of tree line at some locations and filling in of old open forest areas with younger trees near the present limit of trees. Negative effects are more moisture stress on trees and increased insect infestations. Major species are dying over large areas and it is possible that if killed by fire, some areas would not return to forests but would become grasslands. These changes could have great impact on the boreal forests of Alaska. The changes are very difficult to model or foresee due to the widely varying topography and forest types of Alaska and unpredictable ultimate effect of insects and diseases.

Forest Dieback in Russia: Causes, Distribution, and Implications for the Future

O.N. Krankina and R.K. Dixon
Oregon State University, Corvallis, Oregon, USA

Anatoly Z. Shvidenko
International Insitute for Applied Systems Analysis, Laxenburg, Austria

Role of Russian forests in the global environment:

- Forest dieback a major factor in forest resources dynamics
- Causes of forest dieback
- Regional distribution
- Dieback implications per global climate change
- Options to control dieback

Introduction:

- Forest dieback--natural vs. anthropogenic
- Major environmental concern in many regions of the world (Germany, Bohemia, etc.)
- Indication of environmental stress
- Interrelations of causes of dieback
- Forest ecology and mortality
- Role of dead wood in global carbon cycle

Results:

- Regional distribution of dead forests
- Major causes of dieback:
  - Fires (types, distribution, carbon)
  - Pests
  - Anthropogenic factors
  - Pathogens
  - Climate conditions
- Stores and flux of carbon in dead forests: potential increase with climate change

Discussion:

- Implications of data at regional, national, and global scales

Conclusions:

- Forest dieback (both natural and anthropogenic) is a major factor in boreal forest maintenance

- Dead forests play significant role in carbon cycling

- Dieback control measures are necessary to maintain forest area baseline.

The Bor Island Forest Fire: Objectives and Preliminary Findings of Ecological, Atmospheric Chemical, and Climatological Research of a Surface and Stand Replacement Fire in a Boreal Coniferous Forest, Krasnoyarsk Region, Siberia

Johann Goldammer for the FIRESCAN Science Team
Max Plank Institute of Chemistry,University of Freiburg, Freiburg, Germany

The experiment and this paper (with preliminary results) are a joint effort of all the participants of the Fire Research Campaign Asia-North (FIRESCAN). Coordinators of activities were Johann G. Goldammer, Brian J. Stocks, Valentin V. Furiaev, and Erik Valendik. The participants actively involved inpreparing, conducting, and evaluating the field research are listed below.

Per Angelstam, Swedish University of Agricultural Sciences, Riddarhyttan, Sweden
Nikolay S. Bufetov, Novosibirsk Institute of Chemical Kinetics and Combustion, Novosibirsk, Russia
Jim Clark, Duke University, Durham, North Carolina, USA
Wesley R. Cofer, Loyd Overby, and *Edward L. Winstead*, NASA Langley, Hampton, Virginia, USA
Susan G. Conard, USDA Forest Service, Riverside, California, USA
Eduard Davidenko, Russian Aerial Fire Protection Service, Pushkino, Moscow Region, Russia
Xueying Di, Northeast Forestry University, Harbin, People's Republic of China
Michael A. Fosberg, USDA Forest Service, Washington DC, USA
Valentin V. Furiaev and *Eric Valendik*, Russian Academy of Sciences, Krasnoyarsk, Russia
Johann G. Goldammer, Max Planck Institute of Chemistry, University of Freiburg, Germany
Hartmut Gossow, University of Vienna, Vienna, Austria
Anders Granstrom, Swedish University of Agricultural Sciences, Umea, Sweden
Gallina Ivanova, Irina S. Sarkina, and *Igor Vladik*, Russian Academy of Sciences, Krasnoyarsk, Russia
Eino Malkonen, The Finnish Forest Research Institute, Vantaa, Finland
Stein Mano, Max Planck Institute of Chemistry, University of Freiburg, Freiburg, Germany
Steven J. Pyne, Arizona State University—West, Tempe, Arizona, USA
Brian J. Stocks, Gary Hartley, and *Bruce Lawson*, Forestry Canada
Thomas W. Swetnam, Suzanne Swetnam, and *Christopher Baisan*, University of Arizona, Tucson, Arizona, USA
Ross W. Weln, University of Alberta, Edmonton, Alberta, Canada

The FIRESCAN Science Team can be contacted through

Johann Goldammer, Fire Ecology Research Group, Max Planck Institute of Chemistry, University of Freiburg, D-79085 Freiburg, Germany
Telephone: 49-761-808011
FAX: 49-761-808012

Fire is an important natural and anthropogenic factor in the dynamics of the boreal forest system. The ecological and environmental impacts of boreal fires depend on fire weather, fuel availability, fire behavior, and history of stand development (frequence and size of fires and other biotic and abiotic disturbances, influence of surrounding landscape on successional developments). About 70% of the global boreal forest is in Eurasia, almost all of it in the Russian Federation. It is estimated that, in years with high fire danger, up to about 10 million ha of forest and other land in the Russian Federation are affected by fire. The demand for reliable information on the role of natural and anthropogenic fire and the necessity to develop adequate fire management systems is basically due to globally increasing concerns about (1) impacts of boreal wildfires on atmosphere and climate, (2) changing utilization and ecologically destructive practices in boreal forestry, and (3) possible consequences of global climate change on the boreal forest system.

In 1993, the Conference on Fire in Ecosystems of Boreal Eurasia and the subsequent Fire Research Campaign for Asia-North (FIRESCAN) were organized in tandem in the Krasnoyarsk Region, Central Siberia. The aim of the conference was to compile, discuss, and publish the state of knowledge on fire in boreal ecosystems, particularly in Eurasia.

The research campaign was designed to investigate hypotheses developed by the International Boreal Forest Research Association (IBFRA), Stand Replacement Fire Working Group. These hypotheses are related to understanding quantitatively boreal ecosystems, the role of fire in boreal ecosystems, and modeling and predicting forest dynamics. The involvement of atmospheric scientists through the structures of the International Global Atmospheric Chemistry (IGAC) Programme, a core project of the International Geosphere-Biosphere Chemistry Project. On 6 July 1993, an experimental forest fire was set on Bor Island Forest, Krasnoyarsk Region. First results of the experiment are given. The medium- to long-term objectives of follow-up research are described and implications for fire management polices are discussed.

NASA Multisensor Aircraft Campaigns for the Study of Forest Ecosystems

Samuel N. Goward
Laboratory for Global Remote Sensing Studies, Department of Geography, University of Maryland, College Park, Maryland, USA

Darrel L. Williams
Biospheric Sciences Branch, NASA Goddard Space Flight Center, Greenbelt, Maryland, USA

A forthcoming special issue of *Remote Sensing of Environment* is dedicated to results from research carried out under two NASA-sponsored multisensor aircraft campaigns (MAC's) focused on forest ecosystems: the FED (forest ecosystems dynamics,) study, which focused on a research site near Howland, Maine, and the OTTER (Oregon transect terrestrial ecosystems research) study, which examined the vegetation gradient in western Oregon.

NASA supports a variety of aircraft-based remote sensing instruments directed toward exploring possible future space-based observatories for terrestrial research. In recent years, NASA has actively pursued study sites where numerous investigators coordinate their research objectives and activities, and supporting aircraft flights are concentrated in multisensor aircraft campaigns. This approach not only makes for more efficient use of aircraft hours, but also fosters cross-collaboration of research activities between scientists of diverse interests and expertise.

The OTTER and FED MAC activities were developed at about the same time and were carried out during the growing seasons of 1989 and 1990. In both cases, the objectives were to study forest ecosystems to better understand the contribution that remotely sensed observations can provide in ecosystems research. The diversity of research encouraged by MAC studies is well demonstrated in these reports. Not only are all portions of the electromagnetic spectrum considered, but the scales of analysis extend from plant cells to the 200-m Oregon Transect.

BOREAS:
Boreal Ecosystem Atmosphere Study

Darrel L. Williams, Forrest G. Hall, and Pier J. Seller
Biospheric Sciences Branch, NASA/Goddard Space Fight Center, Greenbelt, Maryland, USA

BOREAS is a 4-year regional-scale experiment, starting this year, to study the forested continental interior of Canada. The objective of BOREAS is to improve our understanding of the interaction between the earth's climate system and the boreal forest at short and intermediate time scales, in order to clarify their role in global change. BOREAS will focus on better understanding the biological and physical interactions between the boreal ecosystem and atmosphere that govern the land-atmosphere exchange of energy, water, carbon, and greenhouse gases. More specifically, BOREAS will address (1) the biogeochemical cycles underlying land surface- atmosphere interactions and ecosystem dynamics, (2) the energy water cycles underlying these interactions and their implications for climate change, and (3) the implications of climate change for boreal ecosystem structure, function, and dynamics. In addition, BOREAS will develop and test satellite remote sensing algorithms to transfer our understanding of the above processes from the local scale to regional and global scales.

BOREAS will deploy field campaigns in the winter and summer of 1994, followed by at least two years of coordinated, interdisciplinary analysis of the data. About

75 investigation teams will be funded within BOREAS, including forest ecologists and ecophysiologists, atmospheric physicists, boundary layer meteorologists, hydrologists, biochemists, atmospheric chemists, and remote sensing specialists. BOREAS is being led jointly by NASA and the Canada Center for Remote Sensing with significant involvement from a number of other US and Canadian agencies. The US/Canada combined budget will total about $35 million over the next 4 years.

Reforestation Trials in the Russian Far East

Robert F. Lowery
Weyerhaeuser Co., Tacoma, Washington, USA

In May 1993, some 800,000 container seedlings were given to the Khabarovsk Territory Forest Service for operational planting by several forestry organizations. The seedings were grown from seeds collected in the Russian Far East and were shipped, frozen, to the port of Vanino. Planter training preceded the June/July operational plantings. The concepts of planting project management and planter compensation based on planting quality and quantity criteria also were successfully introduced and used. Results from research plantings of 1991 and 1992 demonstrated the potential of high-quality seedings of local species for reforestation in this area. Late-1993 follow-up evaluations will verify the performance of these various plantings.

Response of Arctic and Arctic–Alpine *Picea* to Recent Climatic Change in Northwestern Canada

Glen M. MacDonald
McMaster University, Department of Geography, Hamilton, Ontario, Canada

Between 1880 and 1940, summer temperatures in the Arctic and subarctic zones increased by approximately 1.2 °C. The rate and magnitude of this warming make it an useful comparative analog for transient changes during future warming due to increases in atmospheric CO_2. Tree ring records of the establishment and radial growth of white spruce (*Picea glauca* (Moench.) Voss.) and black spruce (*Picea mariana* (Mill.) B.S.P.) have been combined with historical records provided by 18th- and 19th-century explorers to reconstruct the impact of this recent climate warming on treeline forests in northwestern Canada. The radial growth of both *P. glauca* and *P. mariana* increased markedly between 1880 and the 1940's. At Arctic and Alpine-Arctic sites, there is little evidence of expansion of *Picea* either northward or to higher elevations. However, there has been also a pulse of recruitment/establish-

ment that produced denser tree cover at the extreme northern and elevational limits of tree growth. Such rapid density changes have been detected in fossil pollen records of earlier episodes of climatic warming at the treeline. These data for past responses of the treeline to climatic warming suggest that the transient response of treeline vegetation to future warming may be quite rapid.

Global Role of the Russian Boreal Forests: A Viable Assessment

Anatoly I. Pisarenko
Federal Forestry Service of Russia, Moscow, Russia

Valentin V. Strakhov
All-Russian Research and Information, Center on Forest Resources (ARICFR), Moscow, Russia

The boreal forest lands of the Russian Forest Fund measure about 900,000,000 ha, but The The boreal forest lands of the Russian Forest Fund measure about 900,000,000 ha, but assessments of the forested area within it vary from 400,000,000 to 600,000,000 ha, depending on the criteria applied to mark them out. The lower estimate (400,000,000 ha) is associated with a definition of "boreal forests" that includes the sub-zone of northern taiga, where the average annual temperature is estimated to be +1.2 degrees C and the average annual precipitation equals 315 mm. The upper estimate (600,000,000 ha) is associated with an approach by which all the forests growing within permafrost zones are classified as boreal ones. According to FAO, the total closed boreal forest area is 920,000,000 ha, i.e., the Russian share is about 43 to 65% of the total boreal forest area of our planet.

In Russia the boreal zone, at its northern limit, includes what is termed properly tundra, and includes also pre-tundra forests (more than 45,000 ha, but their area is not yet precisely determined).

The pre-tundra forests of the boreal zone are a band of forest vegetation forming a transition from taiga forests to the tundra measuring some 30 to 400 km wide. In the administrative context the pre-tundra forests were classified as such in 1969, but in the Russian Forest Fund statistics they are a special item. Their ecological importance is very high: chiefly as an effective factor of soil formation in the Far North. The river systems of the Polar Basin are formed under the influences of these northernmost forests.

In the Earth's boreal zone, the balance between rates of photosynthesis and plant respiration and the rate of decomposition of organic matter by microbial communities has drifted (due to climatic matter peculiarities) toward photosynthesis. As a result, the accumulation of organic matter has predominated, i.e., the so-called sink of carbon exceeds its emission. As George A. Zavarzin has noted, this fundamental property of boreal ecosystems moves the examination of the problem of origin of global climate changes from the national level to the international one, as stated by the Intergovernmental Panel of Experts on Climate Change (headed by Bert Bolin).

So, it is quite natural that international efforts to study global climate change and the losses of biodiversity are focused on the Northern Hemisphere, in the moderate and boreal zones. These efforts mainly tend to study processes of deforestation and forest degradation. That is why it is absolutely clear that these processes are for the UN experts the principal cause of the increases of atmospheric CO_2, the main ingredient of

greenhouse gases.

The position and the extent of the territory of Russia on the Eurasian Continent determine an unavoidable involvement of this country in the study of this world-wide problem and of consequences for the biodiversity, life quality, and economic development. Russian boreal forests growing on boreal and permafrost soils cover about two-thirds of the area of global boreal forests. Beyond a doubt, analysis of the effects of human civilization on the global environment would be incomplete without taking into account natural and anthropogenic processes in the Russian boreal forests. The extent of the Russian territory and the insufficient data about many of its parts, especially in the boreal zone, make realistic evaluation of the global role of Russian boreal forests important in the years ahead.

During the last decade, each year not less than 1,000,000 ha of Russian forested lands were lost. Annosus root rot (caused by *Heterobasidion annosus*) has invaded huge areas of pine and spruce stands in European Russia. According to recent data, the economic damage due to forest degradation is worth about 20 billion rubles per year. Unwise forestry policy leads to an essential worsening of species composition. For example, during the last 25 years the area of pine forests of the Siberian Far East decreased almost by one-third. Many factors could lead to irreversible changes in the Russian forests, even in the near future: (1) the depletion of forest resources, (2) the powerful anthropogenic impact, (3) annual losses of 2 to 3 million hectares of forest to diseases and pests, (4) losses of more than 9,000,000 ha to industrial emissions, (5) losses of more than 4,000,000 ha to forest fires, (6) the global climate changes currently underway, (7) radionuclide pollution of more than 7,000,000 ha of forest lands, and (8) the difficulty of centralized control of forest utilization and forest restoration.

Current Results of Studies of the Russian Boreal Forests

In the commonly accepted sense, in Russia a countrywide forest inventory has not been done; what is available is information from the State Forest Account (SFA). The SFA is based on periodic summaries of data obtained for forest management planning; for forests that were not managed, data are based on airborne evaluations of forests and satellite imagery. The 5-year periodicity of management activity was determined by the need for obtaining survey data on regions, territories, and republics for the beginning of a new 5-year plan.

The peculiarity of the SFA activity in Russia results from the predominance of visual (not instrumental) evaluation of forest characteristics, accompanied by a systematic error, especially when evaluating the growing stock. The formulation of values to record in the SFA is linked to the administrative status of the Forest Fund lands for the different levels region, territory, and republic constituting the Russian Federation, which lessens the applicability of SFA materials. Cartographic support, necessary for precision and valuable for accounting, planning, and managing forests, is not sufficiently included in SFA activities. It needs to be understood that the existing forest inventory system is practically exhausted: it is unable to surmount the major contradiction between a real forest management on area-related principles (requiring first of all a consistency of cartographic information and forest evaluation data) and planning and accounting works in digital terms, which are not closely linked to maps. As a result,

we often have decisionmaking that is unbalanced and not optimal for the forest management policy at different administrative levels.

Now, the latest SFA is carried out in Russia (the earlier one was done in 1988 in the USSR). It states that the total area of Forest Fund lands is 1,182,500,000 ha, including 771,000,000 ha of forested lands, i.e., 18.9% of the overall forest area of the Earth (4,081,500,000 ha according to the World Resources Institute 1991).

The Forest Fund of Russia was completely reviewed only in 1973. More than half of all Russian forests grow on permafrost soils in Siberia and the Far East. This fact explains the low productivity (247,000,000 ha are stands of 5th height class) of these forests. Only 55% of these forest lands are of interest for exploitation, but the bulk of them, which are located in European section of Russia and along the Trans-Siberian Railroad, are already exhausted. Reserved forests (mainly larch stands) are situated predominantly in northern and mountainous areas of Siberia and the Far East. Of the overall area of the Forest Fund, only 17.7% is in the European and Urals part (EUP) of Russia. Forested terrains are distributed as follows: 166,000,000 ha (21.5%) in the EUP and 605,100,000 ha in the Asian part.

The Forest Fund in several regions of Russia has been studied insufficiently, because of the limitations of applied methods of inventory practice as well as the specific generalization of Forest Fund account categories when enlarging the size of area to describe. To the greatest extent, it is true for values of growing stock and stock increment, and consequently, categories of forest land productivity (site classes). When getting larger and generalizing data of forest inventory, the information is summarized into categories describing general species composition at the level of region, territory, or republic: conifers, hardwoods, softwoods, planted stands unclosed (with indication of main species), forest nurseries, and plantations. For a long time, when summarizing inventory data at the level of a region, mixed (hard/softwood) stands with 30% and more of conifers in the growing stock were listed as coniferous forests. Upgrading the lower level to 40% (as recommended for the new cycle of forest management) would lead to a statistical reduction of area and growing stock of softwood forests by not less than 10% at the Russian Federation scale. This would be especially true for regions of traditionally extensive forest utilization by clearcutting in the EUP.

According to the last inventory (January 1, 1988), the Russian Forest Fund had explored and managed 698,200,000 ha, i.e., 59% of its total area. The remainder (484,300,000 ha) was not managed, and it was explored with different methods, including aerial visual observations (during the 1950's and 1960's) and office decoding and deciphering of aerial photographs. Forest Fund areas explored with these simplified methods are usually far from transportation ways, and access is difficult. In the Northern Economic Region, exploration by simplified methods has covered 11.6% of all its Forest Fund; in Komi Republic, 9,600,000 ha; in Karelia, 100,000 ha; in Murmansk Region, 1,600,000 ha; and in Arkhangelsk Region, 900,000 ha. In the West Siberian Economic Region, such exploration has covered 19.3% of its Forest Fund; in Tyumen Region, 27,400,000 ha; in Novosibirsk Region, 1,000,000 ha; in Kemerovo Region, 100,000 ha; in Omsk Region, 100,000 ha; in Tomsk Region, 200,000 ha; and in Altai Territory, 300,000 ha. In the East Siberian Economic Region, such exploration has covered 45.7% of the

Forest Fund; in Irkutsk Region, 22,800,000 ha; in the Krasnoyarsk Territory, 117,400 ha; and in the Tuva Republic, 3,700,000 ha. In the Far East Economic Region, 58.4% of the Forest Fund has been explored; in the Khabarovsk Territory, 30,000,000 ha; in the Magadan Region, 71,800,000 ha; in Amurskaya Region, 300,000,000 ha; in the Sakhalin Region, 300,000 ha; and in the Yakutia (Sakha) Republic, 194,000,000 ha.

In accordance with the "Guidelines of the Forest Legislation" of the Russian Federation (enacted March 6, 1993), the Forest Fund is Federal property and administered by a special body, the Federal Forestry Service of Russia (*Rosleskhoz*). The Rosleskhoz is the legal descendent of the Ministry of Forestry of the Russian Federation. With respect to reforms underway in this country, the Rosleskhoz does not deal with the timber industry (harvesting and timber processing), but its function is the state control of the National Forest Fund.

The forestry administrative bodies have controlled (as of January 1,1988) 1,085,719,000 ha of Forest Fund lands, including 691,500,000 ha of forested area (89.7% of the area of all Russian forests, including 37,400,000 ha put at the long-term disposal of other agencies, 22,700,000 ha attributed to the former USSR Ministry of Timber Industry, 26,700,000 ha to the *sovkhozes* [state-owned farms], and 15,000,000 ha to the *kolkhozes* [collective farms]). About 16% of forest area is deemed inaccessible for utilization (most mountain forests and soil and water protection forests).

As of January 1, 1988, there were 1,648 forestry enterprises managing the Russian Forest Fund. At the lower rank of forest control, there were 7,615 forest districts and equivalent units. At present, the basic unit of forest management is the *leskhoz* [district forestry enterprise]. Forest districts are its spatial constituents. The main ecological and economical feature of Russian forest resources is the discrepancy in their distribution over the country and the productivity and distribution and density of human population. Consequently, the average area of a forest district is 155,000 ha, though it varies largely in different regions. In the EUP it averages 37,000 ha, varying from 4 to 10,000 ha in forest-poor to 242,000 ha in forest-rich regions. In Siberia and the Far East, forest districts measure several million hectares.

Economic reforms in Russia entail an enlargement of approaches and requirements of all the complex of forest account activity: bearing in mind its completeness, depth, features, and methods of work. It is doubtful that the traditional draft of forest management plans will be useful. It is clear that, with the large spectrum of forest users and market conditions, a large spectrum of standard schemes and multitude of original and not-standard schemes of forest organization and management will develop. Consequently, the sum of local and different "forest management plans" will not be adequate for the single state forest inventory. Thus, the established system of forest accounting, in the new transition economy moving toward a free market will inevitably lose its potential to provide complete, unbiased, and trustworthy information on forest resources, if the forestry system is not timely transformed into a three-level state system that includes a Forest Fund inventory, forest health monitoring, and management of federally owned forests.

The specific economic conditions and changes underway in the structure of Russian property patterns require a preliminary set-up of a national information

environment to realize systematic programs and to implement compact regional models.

Degradation Processes in the Russian Boreal Forests

From 1945 to 1992, the quality of Russian forest resources has declined because of the economically unfavorable substitution of conifers by broadleaved trees through natural regeneration after clearcutting, which has lowered forest yield and produced poorer quality timber. A deficient infrastructure in forest regions provoked, in retrospect, a focusing pattern of forest harvesting with predominance of concentrated clearcuttings. As a result, mature and overmature forests are numerous, the felling age has been lowered practically each year, and all the accessible, productive, and high-quality forests have been cut in the zone of activity of timber industry enterprises.

Now, the forest coverage of the EUP corresponds to the level of 1870's. This means that about one-third of all EUP forests are second-growth, their productivity is now lower than that of first-growth, and hardwoods predominate in the species composition. The majority of forest resources in the Northern and Urals economic regions (67.4%) are now located on the least productive lands. The mean growing stock in the Northern regions measures about 40 m^3/ha. Meanwhile, the major harvesting volume (72%) is taken from these regions. Our calculations show that only during the postwar years (1945–1992) were cuttings operated on 53% of lands of both Northern and Urals economic regions. The area of cutting measures over 90% of forest lands in the Vologda Region, 48% in the Arkhangelsk Region, 77% in the Republic of Karelia, 37% in the Republic of Komi, 33% in the Murmansk Region, etc. Felling in excess of allowable cut during the last 10 years was 3,800,000 m^3/yr in Karelia, 4,100,000 m^3/yr in Komi. During the second half of our century, concentrated clearcutting alone has changed, to the greatest extent, the aspect of the Russian boreal forests.

The influences of such cuttings have become the most evident, in the second half of this century, in the Russian European North and, in recent years in the Asian boreal forests. According to expert estimates, the area of Russian boreal forests decreases by 0.04 million km^2/yr, including 0.02 million km^2 as a result of the planned industrial felling carried out mainly (over 90%) with clearcutting methods by applying heavy aggregate equipment. The soil erosion that takes place after such cuttings eliminates, in fact, chances for natural regeneration and considerably reduces the productivity of lands. Another factor in this situation is the low level of harvesting technologies in use, which leads to a large amount of wood (52 to 53% of growing stock) being left at the cutting areas and about 20 to 30% of harvested timber being lost at log hauling.

In Russia as a whole, the structure of unstocked forest lands as shaped by cuttings and degradation of forests encompasses the following categories: sparse woodland, 58.6%; burns and dead trees, 28.2%; cuts, 9%; and glades and blanks, 4.2%. Anthropogenic/technogenic impacts have mostly affected the Forest Fund and biodiversity of the EUP of Russia. The forest land there makes up 47.3% of European forests. The forests cover 38.5% of the EUP land area (166,000,000 ha). The structure of these lands in the EUP is as follows: cuts, 82.2%; glades and blanks, 96%; burns and dead stands, 5.0%; and sparse woodlands, 3.2%. Mean growing stock is 122 m^3/ha. The average annual increment

is of 1.9 m^3/ha, the harvesting is being operated at almost the same rate. The decrease rate in growing stock due to forest mortality from industrial emissions is an average of about 0.1 m^3/yr; that due to forest fires is 0.2 m^3/yr. During the postwar years, cuttings were operated on 49% of stocked forest area of the EUP, i.e., each second hectare was cut.

Not less than 20,000 km^2 of the boreal forest zone are damaged annually as a result of fires. Having been a natural component in the dynamics of boreal forests, forest fires turn now into a factor of anthropogenic degradation. The fire-danger rating increases in the newly developed forest regions everywhere. The considerable part of the boreal forest zone in the Asian part of Russia is not protected by aircraft, and many forest fires are not even taken into account by the forest fire service. The fires severely damage the reindeer pastures. During the last 20 years, about 15,000 ha of the latter have been devastated by fires in the EUP. The area of reindeer pastures has been reduced in the Taimyr Peninsula as a result of fires by 700,000 ha and in Evenkia by 3,000,000 ha.

The pretundra larch forests, especially those of the cladonia type, are highly predisposed to natural fire danger. This can be explained by the large amounts of combustible matters on the ground. Only in the north of Western Siberia (in the regions of oil and gas extraction) about 1,300,000 ha of forest lands and 900,000 ha of reindeer pastures were affected by fires between 1988 and 1990.

In the changing of the landscape features of the Russian boreal forests, anthropogenic and technogenic transformations are, according to expert estimates, damaging not less than 10,000 km^3 of boreal forests every year. The main feature of degradation in the boreal zone of Russia is the appearance of damage foci. Their dimensions vary rather substantially, from several hectares (boring sites, small leakages of oil and bore-mortar, etc.) to hundreds of thousands and millions of hectares (large industrial enterprises). Within the next few years, we should expect that some zones of the impact pollution will merge, for it is highly unlikely that existing development practices in the Russian boreal forests would change quickly for the better. Undoubtedly, this feature will have an effect on all global biospheric processes.

The bad condition of the natural environment in these regions is aggravated by an extremely unstable energetic equilibrium of landscapes. Over three-quarters of Russian forests grow on soils formed on permafrost rocks and in zones of insular or lensing permafrost. Timber harvesting and gas and oil extraction in these forests cause catastrophic changes of plant and animal habitats. In excessively wet regions (very important parts of northern and middle plain taiga), cuttings, borings, and tracts with destroyed vegetation cover develop into swamps. Consequently, there are essential changes in radiation, heat, and water balances of vast areas. Changes occur in the albedo of underlying surface, the dynamics and intensity of surface and underground runoff, evaporating capacity, and the dynamics of heat flows to the ground. The temperature of soils and the ground rises in the summer along with the mean annual temperature). It increases the thickness of the layer of seasonal permafrost thawing, and the defrostration of underground ice lodes leads to a pitting of the surface (thermocarst). When the protection of slopes by tree roots is lost, intensive processes of thermo-erosion begin (solifluction, creep, linear erosion, etc.), and landslides, landfalls, and other exodynamic processes become more active. Moreover,

while the surface is naked (when the snow cover is removed or is packed in the cold period), soil frosting increases and swelling and frost fissuring of the surface are intensified. Owing to these processes, the landscapes change irreversibly and soil and plant cover may be completely lost—turned to badlands with different energy characteristics and moisture exchange patterns. The consequences of such alterations may be detrimental to local climates and engender accumulated climatic disbalances and changed habitat conditions of forest-forming species (first at juvenile phases), and, as a result, may lead to irreversible disturbance of processes of natural forest restoration.

The Carbon Sink and Biodiversity in the Russian Boreal Forests Problems of Assessment

Forests are able to absorb excessive carbon emissions (such as excess atmospheric carbon dioxide) because of plant photosynthesis. The boreal forests, because of the climatic peculiarities of their habitats, could accumulate practically unlimited amounts of carbon in growing and dead wood. The rate of this process may be influenced by human interference such as proactive policies of managing photosynthetic surfaces on the Earth either by planting new forests or by reducing rates of deforestation and degradation of existing forests.

Apart from real or projected global climate changes, nowadays landscape transformation of Russian boreal ecosystems is accompanied by crucial changes in the carbon balance, radiation, heat, and water balances over vast areas. In this connection we should mention that the influence of processes of species change occurring at the large areas of boreal forests, especially on the European North of Russia, upon the carbon balance, as well as upon the function and degradation of boreal wetland ecosystems is yet studied to a least extent. All this leads to loss of biodiversity—this fundamental property of biological systems at any level of organization, from a molecule to ecosystems. With such losses—both in absolute abundance of species and of genetic variability and in the functional importance of diversity in maintaining ecological equilibrium—the life quality of human populations and humanity as a whole could be greatly diminished.

The existing biodiversity of species in the Russian boreal forests is a result of a long evolutionary process, the time scale of which is vastly longer than the scale in which global climate changes are expected to occur. The projected climate warming will affect first of all the reproduction processes in tree species: flowering, pollination, ripening, and seed dispersion. In its turn, changes in the reproduction process and juvenile phases of seedlings' growth could affect the course of the stand formation phase.

To a considerable extent, the boreal ecosystems of Russia are conservative, and with their inertia they could not adequately reshape themselves under climatic factors' effects. Possible response of forest boreal ecosystems on a direct effect of CO_2 concentration rise and of climate changes should be examined from the standpoint of forest exploitation and timber consumption trends. In Russia, until recently, the bulk of timber has been harvested by concentrated clearcutting. Afterwards, reforestation progresses by species succession, and for some period after felling, conifer stands are replaced by pioneer species such as birch and aspen. From an economical viewpoint, this particular succession is qualified as undoubtedly negative, even thought ecologically speaking it is natural. The influence of species succession due to natural

and artificial restoration of forests and to changes in land use patterns (affecting first of all wetland ecosystems) is not yet duly studied.

Therefore, there is need to estimate comparatively the contribution of Russian boreal zone hardwood and softwood forests into the carbon balance and biodiversity protection, bearing in mind their ecological and economical evaluation.

Conclusions

The main feature of degradation in the boreal zone of Russia consists of the development of damaging foci. Their dimensions vary substantially, from several hectares (boring sites, small leakages of oil and bore-mortar, etc.) to hundreds of thousand and millions hectares (large industrial enterprises). In the countries of Western Europe and North America the degradation of northern forests is due to progressive increasing of background air pollution. In Russia, where the background state of atmospheric air on the North may be deemed more or less favorable, a very intensive forest degradation occurs in the vicinity of industrial centers. For the time being, these foci are not numerous, distances between them span hundreds and even thousands of kilometers, and their area does not exceed 1% of the total area of boreal forests. Their negative influence upon the forest ecosystems became essential over areas tenfold and hundredfold exceeding the foci of impact pollution.

Within the next years, we should expect that some zones of the impact pollution will be spatially merged because it is highly unlikely that existing practices to develop territory of the Russian boreal forests would be quickly changed to the better, especially in the old industrial areas, where both improvements of technologies and changing of psychological attitude to boreal forests are needed. Therefore, it needs to expect an aggravation of degradation processes in the Russian boreal forests in the next few years. Undoubtedly, it will have an effect on all the global biospheric processes.

Acid rains and other anthropogenic impacts on the boreal forests in Europe, Asia, and America have brought to light the conclusion that the fragility of these forests and their unprotectedness against human intervention are not less than those of tropical forests. In this context, there are more affinities than differences in the tropical and boreal forests. It is urgent to assess the contribution of the Russian boreal forests into the global CO_2 balance. Although there is no international inventory of boreal forests following unified methodological principles over all the Northern Hemisphere (circumpolar forest inventory), many problems of their study and their assessment will be to discuss.

To all appearances, we should examine the setting up of a unified world-wide system of information on forest health (first of all in the boreal zone) as affected by ecosystem anthropogenic degradation, bearing in mind environmental, biospheric characteristics of boreal forests, their importance as the source of biological raw material, and their changes as linked with regional and global processes. It would allow, on the one hand, assessments of the global importance of boreal forests of the Earth as a whole and of Russia, in particular, as referred to problems of carbon balance, global climate changes, and impoverishment of biodiversity.

On the other hand, only by using such a system would it be realistic to assess the unique and vulnerable habitats and the eventual risk of species extinction due to

observed and expected dynamics of Russian boreal forests. Drawing up criteria of optimal use of natural resources associated with lands of Russian boreal forests as guidelines for investments in the national economy (first of all into sectors of raw extraction) would help provide for well-balanced development of regions, including privy business enterprises, avoiding damages to carbon balance, biodiversity, and the quality of life of small ethnic peoples dwelling the boreal zone of Russia.

The Principles and Methods of the Integrated Protection of Siberian Forests From Destructive Insects

Alexander Isaev
International Forestry Institute, Moscow, Russia

The forests of Siberia occupy a considerable part of the Asian mainland. Their role as a major proportion of the world's forests producing biomass and oxygen is increasing on a vast scale. The intense development of Siberia's resources makes the problem of the preservation of its taiga forests and the increase of their productivity ever more urgent. An important part of this problem consists of the protection of forests from destructive insects.

The mass reproduction of destructive insects in the Siberian taiga forests should be viewed from two angles: (1) as proliferative, pan-zonal outbreaks of dangerous wood pests occurring from time to time, owing to the favorable interaction of natural factors involved in the relationship of the insects with certain types of forest biogeocenoses; and (2) as the result of human economic activities and changes in the ecological conditions in the forest. In view of the current, large-scale development of taiga territories, the problem of the mass proliferation of destructive insects as a consequence of the natural dynamics of taiga ecological systems continues to be of great significance.

The potential danger of mass outbreaks of blight and pests in the Siberian taiga zone arises from the peculiarities of the climatic conditions and the vast tracts of ecologically relatively homogenous conifer forests. Hence, the influence of insects over the Siberian conifer forests is sometimes so great that it not only leads to the loss of growth in biomass, but also to changes in the type of forest associations. The repeated outbreaks of the Siberian silkworm (*Dendrolimus sibiricus* tschv.) and the big coniferous longhorn beetle (*Monochamus urussovi*) in several regions of Siberia from time to time have, to a large extent, determined the present appearance of coniferous forests, their composition and condition, and the dynamics of the process of restoring the forest.

The mass proliferation of destructive insects often assumes the character of natural calamity. As a result of the outbreak of the Siberian silkworm in 1945–1957 and the big coniferous longhorn beetle in 1950–1960, more than 8 million ha of coniferous forest were destroyed in Western Siberia alone. The effects of this “invasion” of these two insects and certain other pests on the forest were so considerable that parts of these areas were dropped from the category of “forest lands” and excluded from the Forest Fund. The drastic changes in the state of the growing of trees led to big losses in the output of industrial timber enterprises, the production of which is based on the long-term use of various forest products.

Human economic activities exert a substantial influences on the population of forest insects in the Siberian taiga zone. This influence neither simple nor uniform affects ecological conditions in the forest. The felling of trees, with the appearance of foliage spaces, road networks, settlements,

and so on, has a divisive effect upon the territory and robs it of homogeneity. Besides, inevitable changes occur in plant make up, with broadleaved species replacing felled conifers on large tracts. This reduces the possibilities for the development of large focal points for the reproduction of many pests. The probability of zonal outbreaks of the insects over large tracts is reduced. In recent years, for example, the Siberian silkworm lost its food base in southern Siberia because of the mosaic pattern caused by the felling of large tracts of forests with coniferous trees. Simultaneously, another destructive insect is growing in significance—the Asian strain of the gypsy moth (*Lymantria dispar* L.) is not only a destructive defoliator of many broadleaved species but also is able to develop successfully among conifers. To recapitulate, economic activities on a vast scale lead to drastic changes in ecological conditions and plant formations, giving rise to new complexes of dendrophilous insects and to changes in the role of some species.

Until recently, the problem of protecting the forests of Siberia was seen mainly in terms of exterminating destructive insects by using chemical, microbiological, and other methods. This was due both to lack of the character of the interactions of insect populations in the system of the forest biogeocenosis, and to the economic necessity for localizing focal points of pests that were vast in area. The elaboration of biogeocenotic principle for analyzing the dynamics of numbers made it essential to revise existing concepts. Forest protection is no longer based on the principle of "combatting" pests, but on the principle of directing the regulation of their numbers, making it possible to make maximal use of the potentialities of the forest biogeocenosis as a self-regulating biological system. This calls for the detailed study of the biology and ecology of potentially dangerous species of destructive insects and of the peculiarities of interaction with ligneous plants.

Scientists at the Forest and Wood Institute of the Siberian Branch of the Russian Academy of Sciences have worked out the theoretical fundamentals of the population dynamics of the most dangerous species of forest insects in Siberia. A new method has been proposed for analyzing the dynamics of numbers based on the principles of the stability of mobile ecological systems. The use of mathematical techniques within the framework of this method allows for simulation modelling of the mass reproduction of insects in a concrete situation, and for estimation of their potential influence over forest ecosystems, taking due account of the economic activities of man.

In analyzing mathematical models, researchers determined the characteristic points in the dynamics of numbers, including the "critical" density of populations, at which the given species causes perceptible economic damage. It has been established that the regulation of numbers of pests at the stage of "critical" density may be accomplished not only by means of poisonous chemicals, but also by using repellents substances with a limited spectrum of effect which make insects shy away. The decrease in numbers of insects to dispersed populations below the critical level restores stability to biogeocenoses and more or less eliminates the risk for destruction of the valuable stands.

The specific problem peculiar to the forest protection service in Siberia is to control the dynamics of the numbers of many species on a vast territory. This emphasizes the importance of measures aimed at forecasting changes in the activities of species and necessitates the wide use of remote sensing methods. According to pre-

sent estimates, active forest-protection measures connected only with preventing a mass outbreak of the Siberian Silkworm, should in certain years cover a territory of 150-300 million hectares. The solution of such tasks obviously calls for essentially new methods for collecting information on the condition of various forest tracts. These methods are being worked out with the use of special kinds of aerial survey (aircraft, satellites). These methods enable a total estimate of the degree of danger to the growing tree to be made. Land and air diagnoses of forest conditions provide a base for modelling the dynamics of the number of pests, show the extent to which tree may be potentially damaged, and indicate the optimum economic measures. Such system of forest protection measures has been worked out by scientists. The system underwent tests under field conditions with the suppression of mass outbreaks of the Siberian silkworm and of the big coniferous longhorn beetle in the fir forests of Krasnoyarsk Territory in 1967 1970 and is now being widely used in the practice of forestry production.

The system of the integrated protection of Siberian forests includes inspection of the changes occurring in the numbers of pests; short-and long-term prognosis of the possibility of mass outbreak; exterminatory measures (chemical and biological) and methods for assessing the efficiency of these measures and their ecological consequences. This system was applied very rigorously to the main destructive insects of taiga forest the Siberian Silkworm and the big coniferous longhorn beetle. In its elaboration such important factors were taken into account as the distinctive character of forest protection in the less developed taiga forest lands, the present significance of measures of inspection and prognosis and the large-scale use of aerial methods, providing for the timely discovery and localization of the focal points of the reproduction of destructive insects.

In its general form the system of the integrated protection of the forests of Siberia includes:

1. The integrated method of long-term forecasting, based on statistical reliability of the conjunction of mass proliferation of the Siberian silkworm with drought in June and July, when the development and pupation of the caterpillars and aestivation of butterflies takes place. The long-term prognosis covers a minimum period of 2 to 3 years and its reliability is over 80%.

2. Numerical methods of short-term forecasting based on annual estimates of the number of insects and the complication of probable models for the development of the focal points. The extent of the possible danger to plants is established on the basis of the information and the expediency of carrying out exterminatory operations is then decided.

3. The strategy of choosing optimum variants of aviation-chemical and bacteriological protection of taiga forests, which are determined by the peculiarities of the forest-growing conditions of the region and the numbers of destructive insects. Four basic strategic variants of aviation chemical and aviation bacteriological combat are prominent.

a. The strategy of selective processing consists in the timely and qualitative processing of primary foci of pests disclosed by aerial survey and land observations. This strategy enables the volume of protective work to be greatly reduced and makes it possible to exterminate the foci of before much damage is done.

b. The strategy of partial processing is variant for destroying the most dangerous foci of pests in the period when the outbreak is on the decline, making it possible to reduce sharply the volume of aviation

protective work.

c. The "anti-combat" strategy is based on the maximum possible restriction of protective measures reducing the threat of saturating taiga biogeocenoses with pesticides. Processing excludes focal points showing marked sign of a reduction in numbers owing to weather conditions and biotic factors (enemies, diseases, etc.). In each concrete case, the assessment of the conditions of the populations of pests was made on the basis of "survival tables," analyzed by means of computers with due consideration for the critical points of the dynamics of numbers characteristic for the given type of forest plantings and the prevailing weather situation.

The selection of strategic variants is based on aerial surveys and ground explorations. At the same time, due account is given to the diagnosis indices of probability and intensity of the outbreak revealed in assessing the trajectory of the numbers of the pests and the analysis of the spectral characteristics of the woody canopy as an index of the condition of the plantings.

In developing taiga territories the integrated protection of forests is regarded as a major element of economic forestry promoting the rational use of the forest reserves of Siberia.